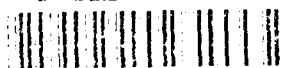


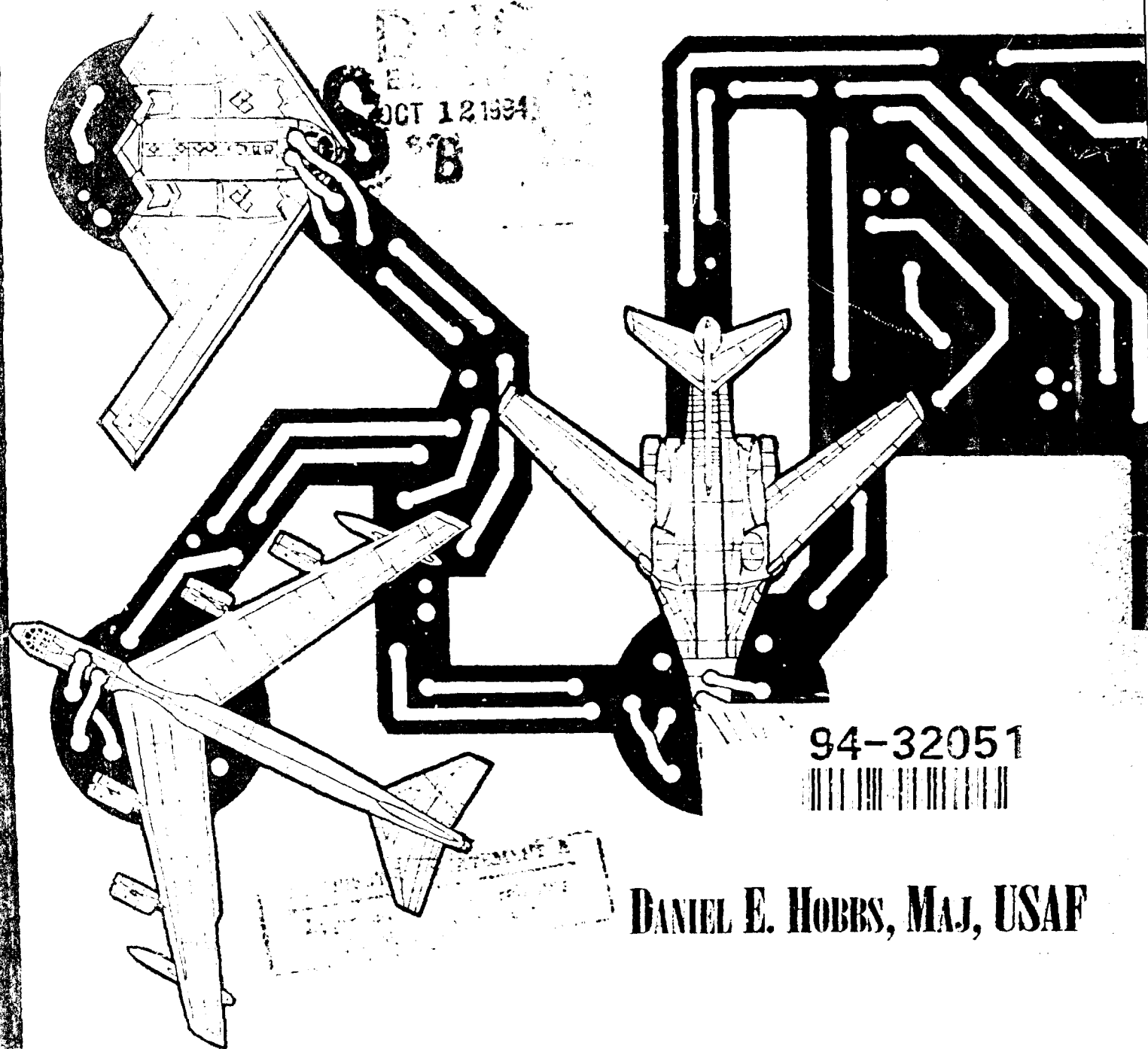
# ADAPTING STRATEGIC AIRCRAFT ASSETS TO A CHANGING WORLD

TECHNOLOGY INSERTION TO PROVIDE FLEXIBILITY

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DANIEL E. HOBBS, MAJ, USAF



Research Report No. AU-ARI-92-10

# **Adapting Strategic Aircraft Assets to a Changing World *Technology Insertion to Provide Flexibility***

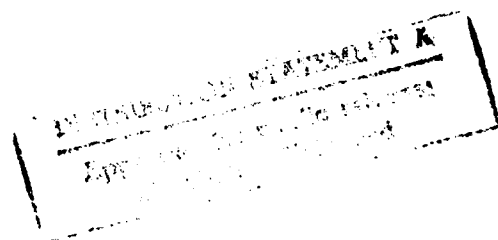
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### ***About the Author***

Maj Daniel E. Hobbs is a native of West Virginia. He graduated from West Virginia University in 1977 with a bachelor of science degree in statistics and a Reserve Officer Training Corps commission. After entering active duty, he attended undergraduate navigator training and navigator bombardier training at Mather Air Force Base (AFB), California, followed by an assignment to Griffiss AFB, New York, as a B-52 navigator. At Griffiss, he earned a master of business administration (engineering management) degree from Rensselaer Polytechnic Institute, in Troy, New York. In 1984 he attended Squadron Officer School and was reassigned to the 31st Test Squadron at Edwards AFB, California, where he flew B-1 and F-111 aircraft in operational and developmental flight tests. His next assignment took him to Strategic Air Command (SAC) headquarters, Air Vehicles Requirements Division, at Offutt AFB, Nebraska, where he served as B-1B avionics acquisition manager. In 1991 he was selected to attend Air Command and Staff College and to serve as a SAC-sponsored research fellow at the Airpower Research Institute.

## ***Preface***

Responding to the changing world order, the Air Force has adopted a new philosophy to expand its 40-year-old strategic triad concept. Gen George Lee Butler, commander in chief, Strategic Air Command (CINCSAC), referred to the new philosophy as twin triad, since it places heavy emphasis on an increased commitment of manned bombers in conventional warfare. To meet this commitment, SAC must improve its conventional war-fighting capability to fulfill its bombers' commitments and to foster its credibility in the view of the rest of the Air Force.

To improve the conventional war-fighting capability of its bombers, SAC must improve its ability to detect and destroy difficult targets, its on board mission management, its communication and navigation capability, and its defense and equipment reliability. Chapter 1 explores these requirements and the reasons behind them. Unfortunately, the Air Force procured SAC's strategic bombers—the B-52, B-1B, and B-2—under the old for-a-one-time, one-way, fly-the-black-line nuclear mission philosophy. SAC's bombers still have a limited conventional capability only. Worse, the on board computers (i.e., the avionics) on these aircraft are specifically designed for the nuclear mission with little or no capacity to accept additional equipment to execute new tasks.

Fortunately, the B-1B, B-2, and, to a lesser extent, the B-52, make wide use of computer software. This means that they employ a considerable amount of somewhat standardized computer hardware and software. Chapter 2 details the avionics of the three bomber types and shows how these computers yield to manipulation through minor hardware and software changes rather than through expensive replacement of either the aircraft or the avionics complexes.

Chapter 3 outlines concepts to manipulate bomber avionics for improved performance. A close study of the various avionics complexes reveals SAC's tendency to improve performance with current technology. These performance improvements include avionics computer speed, memory capacity, and capacity for future growth, which the current systems lack. In addition, restructuring several areas of the flight software can improve performance and provide commonality between aircraft. Chapter 4 shows that well-designed technology insertion ultimately can provide the capability to "tailor" the aircraft in a matter of hours with weapons, sensors, and other equipment for a specific mission. Today, no such tailoring capability exists.

We have spent much time and expense to develop these aircraft for a nuclear mission. Prudence suggests that we use this performance capability for a new system along with technology insertion to give us the best of both worlds. That is, insertion programs can provide a continued (and improved) capability to perform the nuclear mission and the capacity to adapt quickly to almost any new requirement.

Chapter 5 proposes technology insertion programs as a way to improve the bomber force. Hopefully, this will enhance long-range acquisition planning by detailing the major contributions technology insertion into the current avionics can

make with only modest modifications and at minimum expense. We must shy away from advocating technology insertion for a specific mission or relying on technology insertion for technology's sake. The central idea here is that technology insertion improves the flexibility to adapt to whatever missions may evolve for the manned bomber.

A handwritten signature in black ink, appearing to read "Daniel E. Hobbs". The signature is fluid and cursive, with a long horizontal stroke extending to the left.

DANIEL E. HOBBS, Maj, USAF  
Research Fellow  
Airpower Research Institute

## **Chapter 1**

# **A Changing World Environment for Bombers**

The Strategic Air Command (SAC) has reached a pivotal time in American military affairs. Like never before, the world is changing nearly as fast as the mapmakers can produce new maps. In a twinkling of an eye, the cold war has ended, the Soviet Union has dissolved, and we have proved America's strength in coalition with allied forces against desert tyranny. Activities such as these imply an uncertain future. The black and white of yesterday has turned to the gray of today, and our democratic system no longer stands eye-to-eye with the "evil empire." For the military planner, an uncertain future means uncertain threats, which in turn means the planner must prepare for unprecedented possibilities.

More than ever, each of the armed services must husband its resources to ensure that they suffice during an unexpected threat. In a world of decreasing military expenditures, we no longer have the luxury of tailoring military equipment for a specific mission. Each weapon system must have the built-in flexibility to challenge a dynamic world. The bomber is no exception to this rule. The number of bombers in service is at its lowest point since the onset of World War II, and an increase seems unlikely. Each bomber must have a capability to adapt to a changing mission quickly. Also, each bomber must have the flexibility to interact with the right weapon at the right time. To take full advantage of the bombers in its inventory, SAC must begin immediately to build in the required flexibility to meet the demands of a changing world environment.

## **Our Changing World**

The phenomenon SAC faces has many names. President George Bush proclaimed it "the new world order"; the national security strategy pamphlet referred to it in 1991 as "a new era"; and Maj Gen Robert Alexander declared it the time for "a new paradigm."<sup>1</sup> Regardless of the name, SAC must realize the world has changed, and to ensure security, SAC must change its defensive posture also.

General Alexander's old paradigm uses the words *strategic* and *nuclear* as synonyms and *Tactical Air Command* as the designated conventional war fighter. The cold war perpetuated the old paradigm, but now that the cold war is over, General Alexander believes:

The new paradigm that is emerging is an Air Force that is fully integrated institutionally, organizationally, intellectually, and culturally to resolutely and decisively apply airpower at the strategic, operational, and tactical levels.<sup>2</sup>

The impact of the new paradigm goes beyond organization, requiring military force integration that involves the manned bomber in new and diverse roles. These new roles result in a requirement for additional capabilities which are affordable only through the appropriate adaptation of existing systems.

## **The Road to Changing Bomber Roles**

The role of the manned bomber in American defense has come full circle since World War II. During those days, the bombers flew conventional weapons delivery missions, often fighting alongside fighter aircraft. After the war, and because of the advent of the atomic age, bombers took on a life of their own, and SAC arose almost as an independent air force to permit the bombers to fly alone on preplanned missions. The new world order has forced a change to the old SAC philosophy, and once again bombers and fighters fly side by side in a conventional war. Understanding the road we have taken to this new bomber role clarifies why bombers inherited the new requirements to support an expanded conventional commitment.

### **Origins of a Giant**

Though conceived many years before the 1940s, the strategic bombing giant grew to maturity during World War II. During World War I, for example, the French emphasized points sensibles, or sensitive spots (i.e., "legitimate military targets whose destruction would block a critical supply line or production chain").<sup>3</sup> But World War I aircraft lacked sufficient capability to fulfill the French dreams. By World War II, however, the B-17 and other similar aircraft adopted Norden bombsight technology to move closer to the air power doctrine envisioned by the French and American pioneers such as Gen Billy Mitchell. For the first time, these pioneers used significant air power to bring the war to the enemy's homeland and to attack oil fields, aircraft and steel factories, cities, and other strategic targets. In 1945 the US European bombing survey team concluded from these bombing raids that "even a first class military power—rugged and resilient as Germany was—cannot live long under full-scale and free exploitation of air weapons over the heart of its territory."<sup>4</sup>

The Pacific survey team reached similar conclusions about the impact of the air strikes on Japan. But in the case of Japan, the Allies went on to introduce atomic weapons—the ultimate strategic deadly instrument. Successful power projection in the form of strategic air power, when used with the new atomic bomb, convinced the strategic bombing survey teams that:

In addition to the Army and the Navy, there should be an equal and coordinate position for a third establishment. To this establishment should be given primary

responsibility for passive and active defense against long range attack on our cities, industries, and other sustaining resources; for strategic attack, whether by airplane or guided missile; and for all air units other than carrier air and such land-based air units as can be more effective as component parts of the Army or Navy.<sup>5</sup>

This notion not only gave rise to the creation of the Air Force, it established the Strategic Air Command (SAC) as the backbone to this new "third establishment." The creation of the Air Force also made the terms *strategic* and *nuclear* synonymous.

Today, we suffer from a blurred distinction between the terms *strategic* and *nuclear*. Although the concept of strategic nuclear deterrence has served us well since its conception, it forced us to put our bombers in a container where they are no longer flexible. By dedicating the bomber to the single integrated operational plan (SIOP) nuclear mission we have, in Gen T. Ross Milton's words, "to some extent, mortgaged the future of [the] bomber."<sup>6</sup> His statement suggests that the manned bomber has been laid impotent for anything but nuclear warfare (and a minor conventional role) by policies which optimized these aircraft for the nuclear mission.

### **Philosophy through the Years**

How did we arrive at a point where our bomber force is no longer flexible? In short, we arrived there by following the philosophy of strategic bombing and nuclear deterrence that defends our country. This philosophy was preached by Gen Curtis LeMay, a man whose name is closely identified with bombers. He understood strategic bombing concepts well and applied them equally well. Throughout World War II he advocated long-range pinpoint bombing, and he carried the lessons he learned as a field commander to his job as the father of the SAC. In 1986 General LeMay said, "My goal was to build such a well-trained, strong, and professional outfit that we wouldn't have to fight."<sup>7</sup> His extraordinary insight into the employment of air power and his strong personality created an organization that has remained almost the same into the 1990s.

SAC was created in 1946, as the nation demobilized from war and as tension with the Soviet Union increased. General LeMay took command of SAC on 19 October 1948, the year of the Berlin airlift, less than one year before the Soviet Union exploded its first atomic device on 17 September 1949. Thus, born at the beginning of the cold war, SAC has focused its mission on a nuclear deterrent responsibility.

Initially, because of the tremendous threat posed by the expanding Soviet empire, SAC became an air force of its own making, possessing bombers, tankers, airlift, fighters, reconnaissance aircraft, and a promotion system (spot promotions). SAC received its first share of the dollars spent for defense, and General LeMay quickly took advantage of the availability of financial resources and the advance of technology to begin many new aircraft development and modernization programs, including the B-47, the first total jet engine bomber. Before the end of the 1940s, with the addition of an air refueling capability, SAC demonstrated the ability to project air power

worldwide by a nonstop, around-the-world flight on 2 March 1949. SAC's concept of operations, put in place by General LeMay, was a rapid global nuclear response to deter Soviet aggression. An ever-ready alert force of loaded, ready-to-fly bombers made rapid response possible. And although SAC has changed the make-up and posturing of the alert aircraft over the years, it has not changed the concept of alert. In 1988 one SAC historian wrote:

Over the last thirty years, the Strategic Air Command has experienced some remarkable improvements in the weapons with which it performs its mission. Technology has helped the command keep a credible deterrent force ready. Yet, the backbone of deterrence has remained the SAC alert force.<sup>8</sup>

Ironically, General LeMay was known as a man of flexibility. In 1963 the *Air Force Times* proclaimed as much in its article "Flexibility Key to LeMay's Value to Nation During Peace and War," which stated:

Flexibility, cornerstone of Air Force strategic doctrine, is also the key word in assessing the thinking of Gen Curtis LeMay. It is the ability to "reverse his field" when changing conditions demand a new approach to a problem that has helped LeMay move to the top of the Air Force ladder.<sup>9</sup>

General LeMay's philosophy has endured through the cold war. SAC has witnessed great pressure to modernize but few opportunities to enhance the bomber's nuclear war-fighting role. This paradox culminated in 1980 when President Ronald Reagan assumed office and initiated a rebirth of the B-1B and the procurement of a new bomber, the B-2. But the cold war still raged, and these bombers, like the existing B-52, were optimized for nuclear warfare, with little regard for the conventional mission. Not even General LeMay could have anticipated that the world would change so dramatically before SAC could deploy the first B-2; and now, more than ever, SAC again needs to adapt his views on flexibility.

### **The End of the Cold War**

No better indicator of the end of the cold war can be seen than the end of continuous bomber alert. On 28 September 1991, only three years after Gen John Chain, the commander in chief of SAC, proclaimed 1988 as "the year of the alert force." Secretary of Defense Dick Cheney signed a memorandum that allowed bombers to stand down from alert for the first time since they first began their ground alert in October 1957.<sup>10</sup> (The major points of Secretary Cheney's memorandum, which are dramatically reshaping the posture of our strategic forces, are summarized in table 1.) The president's eagerness to capitalize on the end of the cold war has not gone unnoticed by the print and voice media. The Prodigy news service announced, "After two generations of cold war, the US and Soviet Union are engaged in a new type of military competition—a reductions race."<sup>11</sup>

Because many observers believe that "bomber" equals "strategic" and "strategic" equals "nuclear," they see little justification for continuing a bomber force. They argue that the end of the cold war has put to rest the need for a standing nuclear force, particularly for bombers whose job can be done

Table 1

**Secretary of Defense Memorandum  
28 September 1991**

1. THE UNITED STATES ARMED FORCES SHALL ELIMINATE ITS INVENTORY OF GROUND-LAUNCHED THEATER NUCLEAR WEAPONS
2. TACTICAL NUCLEAR WEAPONS SHALL BE REMOVED FROM ALL SURFACE SHIPS, ATTACK SUBMARINES, AND LAND-BASED NAVAL AIRCRAFT BASES
3. UNITED STATES STRATEGIC BOMBERS SHALL STAND DOWN FROM THEIR ALERT POSTURES AND THEIR NUCLEAR WEAPONS SHALL BE REMOVED AND STORED
4. THE UNITED STATES INTERCONTINENTAL BALLISTIC MISSILES SCHEDULED FOR DEACTIVATION UNDER THE TERMS OF THE START TREATY SHALL STAND DOWN FROM ALERT
5. DEVELOPMENT OF THE MOBILE PEACEKEEPER ICBM RAIL GARRISON SYSTEM AND THE MOBILE PORTION OF THE SMALL ICBM PROGRAM SHALL BE TERMINATED
6. THE NUCLEAR SHORT-RANGE ATTACK MISSILE PROGRAM (SRAM II) SHALL BE TERMINATED
7. A UNIFIED COMMAND PLAN WITH A UNITED STATES STRATEGIC COMMAND TO WHICH ALL ELEMENTS OF THE U.S. STRATEGIC DETERRENT ARE TO BE ASSIGNED SHALL BE SUBMITTED TO ME

Source: SECDEF Memorandum, 28 September 1991.

by a combination of intercontinental ballistic missiles and cruise missiles. As further evidence, they note that the B-1B didn't participate in Operation Desert Storm, but was held in reserve for nuclear attack—an unlikely event made even more unlikely by the collapse of the Soviet Union. Finally, some other observers believe the air refueling capability of modern fighters can project enough power to strike the same targets as any bomber could, particularly if the fighters are launched from a Navy carrier. These arguments have some merit, but they ignore some important capabilities only a bomber can bring to a war.

The bomber continues to have the capability to project power any place in the world and to do so faster than any other weapon system. Compared to the F-117, the B-2 can carry sixteen 2,000-pound weapons more than 6,000 miles without refueling, while the F-117 can carry only two bombs a much shorter distance without refueling. And if stealth is not needed, the B-1B can carry even more bombs (up to twenty-four 2,000-pound weapons) roughly the same distance as the B-2. When properly configured, four B-1Bs without tankers could have replaced the squadron of F-111s that attacked Libya on 14 April 1986, risking only 16 crew members on the B-1B as compared to 48 crew members on the 24 F-111s. The bombers can also reach some places the Navy carrier planes cannot. It is easy to visualize scenarios, such as deep-penetration missions within the former Soviet Union, where cruise missiles are not feasible because of target identification. In an instance such as this one, a long-range bomber is the only option. With forward-basing rights and defense dollars becoming increasingly scarce, it may not be affordable to use fighter aircraft to do a long-range bomber's job.

## **The Impact of Desert Storm**

During Operation Desert Storm, US forces had the luxury of parking aircraft loaded with precision weapons only a stone's throw from enemy targets. It's doubtful this opportunity will recur. Still, the B-52G aircraft did not park next to the battlefield, but thousands of miles away, and, interestingly, generally struck targets traditionally referred to as tactical. The Air Force's white paper on restructuring states:

In Desert Storm, they [airplanes] were employed against both tactical and strategic targets. F-117s hit key strategic nodes in Baghdad while F-15Es and F-16s attacked biological and nuclear weapons facilities. And A-10s hit Scud launch facilities. Conversely, B-52s were highly effective against Iraqi ground forces in tactical positions.<sup>12</sup>

The lines between strategic and tactical have become blurred. It is equally evident from Desert Storm that bombers and fighters must perform the same types of missions, particularly all-weather, precision-bombing missions.

From Desert Storm and to the end of the cold war, one can conclude that the role of the bomber has changed dramatically. The nuclear role has not been invalidated, it has been reduced. No longer designated solely for nuclear deterrence, the bomber has a greatly expanded operational concept. There is a burden, therefore, on bombers to compete in future wars. To do this the bomber must be fully integrated into our conventional forces and modernized to meet new requirements.

## **Restructuring for the Post-Cold War World**

The Air Force restructuring white paper states that "the utility of designating some aircraft tactical and others strategic has been overtaken by current capabilities. The organization needs to catch up."<sup>13</sup> Before the advent of nuclear weapons, bombers and fighters fought a theater war. They fought alongside each other to complement the other's capabilities. Technology and the changing world environment have brought us back to a pre-World War II standing. Fighters and bombers are once again coming together to fight wars more efficiently. This union of fighters and bombers has implications beyond organization. The current capabilities mentioned in the white paper may have been more correctly referred to as current capacity. The bombers have the capacity to adapt to these new expanded mission requirements, but they don't all necessarily have the current capabilities. To fight together, they must operate together, sharing equipment, weapons, targeting data, software, and many other logistical items. In short, SAC must improve the interoperability between bombers and fighters to reach the ideal goal of a new war-fighting philosophy.

## **The Twin Triad: A New Philosophy**

Just as General LeMay dealt with a new world order in 1946 by building the philosophy of the original Strategic Air Command on a triad which is

comprised of bombers, intercontinental ballistic missiles, and sea-launched ballistic missiles, Gen George Lee Butler responded to a new world order by outlining the need for change some 45 years later. General Butler concluded that six major forces (table 2) were reshaping the global strategic environment.<sup>14</sup> In his testimony to the House Armed Services Committee in February 1991, two months after his appointment as CINCSAC, General Butler said:

I have spent the bulk of my first eight weeks in office reassessing the corporate vision that has guided SAC for the 45 years of its existence. My conclusion is that while we are still on sound footing, both the seemingly interminable debate over strategic nuclear modernization and the new realities of a changing world order require a fundamental restatement of SAC's missions and requirements.<sup>15</sup>

**Table 2**

**Forces Reshaping the Global Strategic Environment**

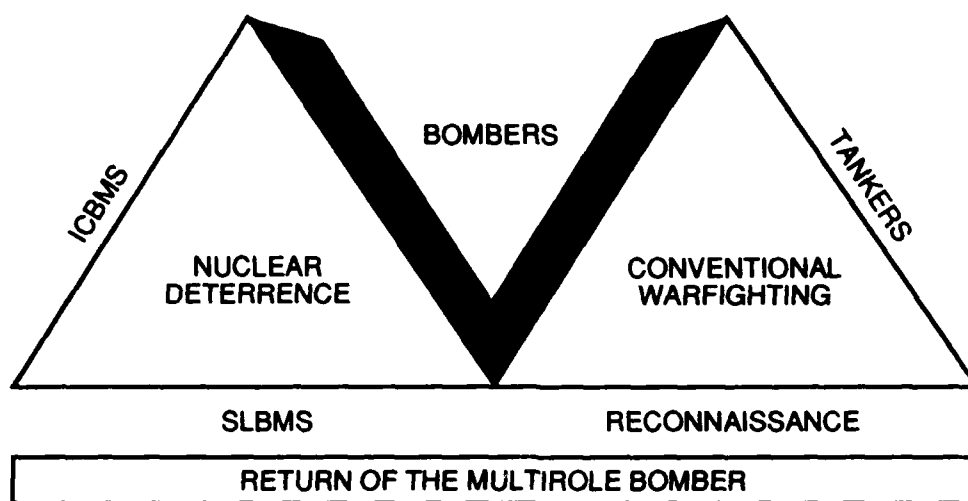
1. Soviet retrenchment and the end of the cold war
2. German reunification
3. The emerging concert of Europe
4. Intensification of regional strife and conflict combined with weapons proliferation
5. Catastrophic failures in the human condition
6. New (competitive) centers of power

**Source:** Gen George Lee Butler, Speech to National Press Club, Center for Defense Journalism, Washington, D.C., 27 September 1990.

From this analysis of what fundamental changes to SAC's mission should be, the philosophy of a twin triad emerged. The second triad has a conventional war-fighting capability comprised of bomber, tanker, and reconnaissance aircraft. To a lesser extent, a conventional capability has always existed in SAC, but the twin triad puts conventional warfighting on an equal footing with nuclear deterrence (fig. 1). After General Butler envisioned the twin triad, the Air Force went a step farther and organizationally restructured the bombers into the new Air Combat Command (ACC), which would share its assets with the new Strategic Command (Strat Comm) in the event of nuclear war. The twin triad has become twin commands: Strat Comm and ACC. Although to many observers this may seem like a subtle change, the implications are far reaching, impacting the basic operating tenants of the bombers and ultimately changing their configuration requirements.<sup>16</sup>

### **Nuclear Deterrence**

As mentioned above, SAC has been mostly concerned with nuclear threat and nuclear deterrence for the greater part of its existence. For the foreseeable future, the threat will continue and will require a nuclear attack



Source: Headquarters SAC, Command Briefing, 1991.

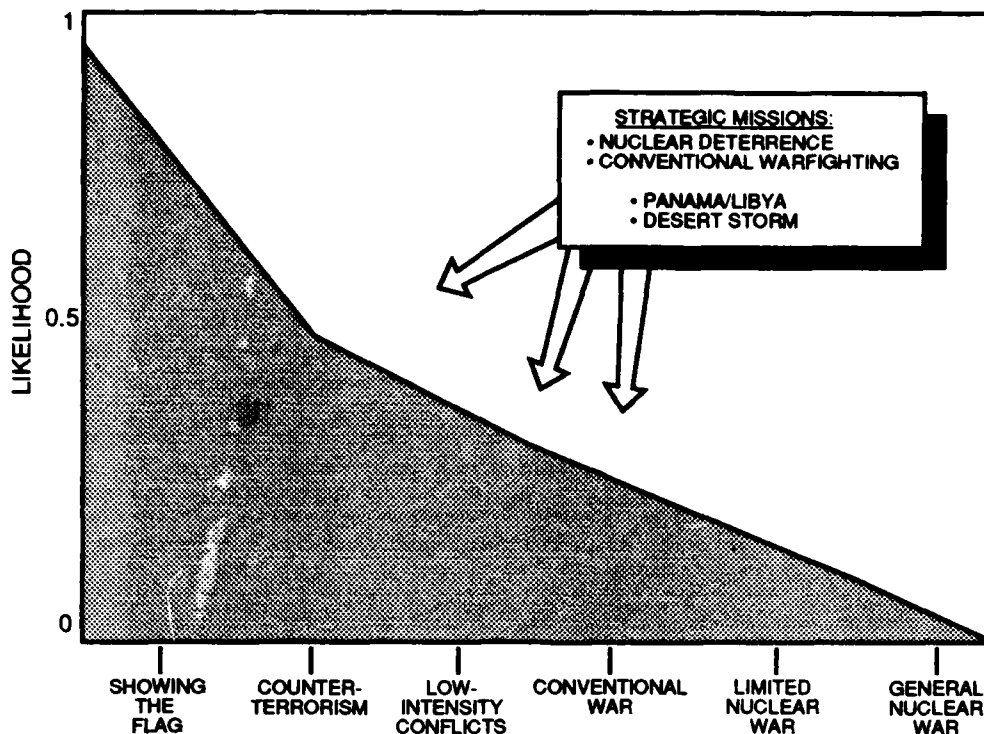
**Figure 1. The Twin Triad**

deterrence. However, the diminishing Soviet threat, a growing world antinuclear attitude, and increasing arms control have combined to reduce the need for a large, standing nuclear force. At the same time a growing potential for conventional warfare looms. Figure 2 shows the SAC estimate of potential conflicts. These facts do not eliminate the need for a nuclear deterrence. A scaled-down SAC, under the name Strategic Command, intends to "maintain a credible, vigilant nuclear deterrent force," and considers nuclear deterrence to be "job one."<sup>17</sup> Maintaining deterrence will, as always, require strong intercontinental and sea-launched ballistic and bomber forces.

The B-52, B-1B, and soon-to-come B-2 comprise the strong bomber forces that are required for nuclear deterrence. Each has complementary attributes optimized from the beginning for the nuclear mission (chapter 2 details each bomber's current capabilities). This capability means the bombers, after they have received permission from the national command authorities, can fly autonomous, deep-penetration missions to deliver nuclear (dumb) bombs or short-range attack missiles. They can fly the entire mission alone (with the exception of refueling) by using self-contained navigation and defense capabilities. Other than the low-level delivery method, the nuclear mission resembles the unescorted strategic bombing raids over Germany during World War II. This mission differs significantly from a mission to support the conventional warfare triangle of the twin triad.

### **Conventional War-Fighting Capability**

The Air Force envisions fighter and bomber aircraft that operate in concert, and not autonomously as bombers have done in the past. More than ever, SAC



Source: Headquarters SAC, Command Briefing, 1991.

**Figure 2. Responding to the Threat**

will integrate the bombers into the conventional strike force to fulfill the tenants of the global reach—global power philosophy which states, “Our force planning calls for an increased emphasis on force projection capabilities—even more flexible, rapidly responding, precise, lethal forces with global reach.”<sup>18</sup> Bombers provide the best tool for a global reach in a conventional war.

The conventional strike mission differs vastly from the single integrated operational plan mission for which the bombers were built. A conventional mission does not always adhere to the preplanned flight path bombers fly on a nuclear mission. Instead, they frequently require several in-flight mission changes before striking the target. In the case of the nuclear mission, once it is executed, the bomber proceeds with little central control. But in the case of the conventional mission, SAC must strictly and continuously control the bomber and maintain communication connectivity. Also, an integrated bomber force should handle some of the same type of precision conventional weapons used by modern fighter aircraft. In other words, the ability to replan in-flight changes rapidly under centralized control with weapons tailored to the target, is essential for the flexibility required for conventional war fighting. Currently, bombers do not achieve the minimum required capabilities.

## Our Uncertain Future and the Need for Flexibility

As mentioned before, by all indications we are entering into a time of tremendous world military uncertainty. The August 1991 national security strategy white paper states:

In the realm of military strategy, we confront dangers more ambiguous than those we previously faced. What type and distribution of forces are needed to combat not a particular, poised enemy but the nascent threats of power vacuums and regional instabilities? How do we reduce our conventional capabilities in ways that ensure we could rebuild them faster than an enemy could build a devastating new threat against us? How does the proliferation of advanced weaponry affect our traditional problem of deterrence? How should we think about these new military challenges and what capabilities and forces should we develop to secure ourselves against them?<sup>19</sup>

Fortunately, these questions posed by the members of the national security council can be answered through prudent planning. Almost simultaneous with the release of the 1991 national security strategy document, Dr Colin S. Gray published some guidance for planning in times of uncertainty in the *Airpower Journal*.<sup>20</sup> Table 3 outlines what Dr Gray calls "principles for guidance in a period of nonlinear change." Chief among these principles, at least with regard to the bomber, is the desire to obtain the flexibility to adjust to the changing circumstances which they now face.

As we adopt a new philosophy to expand the conventional role of the bomber and retain its full nuclear capability, we must increase the flexibility of the individual aircraft. This flexibility includes the ability to load nuclear weapons on one day, and on the next day load the targeting sensors and precision conventional weapons that a typical fighter would carry. Flexibility also entails the ability to data-link bomber-to-fighter, bomber-to-bomber, and bomber-to-home control to receive accurate and timely targeting information. In short, the bomber requires some basic modifications to meet the needs of an uncertain future.

Table 3

### Seven Principles for Defense Planning

1. Face facts, recognize ignorance
2. Apply geostrategic priorities for fault-tolerant planning
3. Recognize that the long term is a succession of short terms
- ★4. Sustain or acquire flexibility to adjust to changing circumstances
5. Learn from the past
- ★6. Play to American strengths
7. Reexamine assumptions, reshape rationales

Source: Dr Colin S. Gray, "Defense Planning for the Mystery Tour: Principles for Guidance in a Period of Nonlinear Change," *Airpower Journal*, Summer 1991, 18-26.

## **New Requirements for New Bombers**

Some observers may question the title, "New Requirements for New Bombers." Hopefully, by this point readers agree that SAC designed modern bombers for nuclear, not conventional, warfare, and because of the expanding role of bombers in the twin triad, several new requirements now exist. We examine them below. The term "new bombers" may confuse some readers because one of the new bombers discussed—the B-52—is more than 30 years old. The B-1B and B-2 are relatively new, especially when observers compare them to the B-52. Surprisingly, these three bombers have roughly the same avionics technology, most of which was designed in the early 1980s. Chapter 2 details the current technology of each of these bombers.

Note that, although each aircraft is fundamentally different from an aerodynamic (or airframe) perspective, each is fundamentally the same from a computer technology perspective, and because of this fundamental similarity, each has roughly the same technological capability to delivery weapons—the primary aircraft mission. Therefore, a discussion of new requirements, based on an expanded conventional commitment, applies equally to all three bombers, regardless of their airframe age.

### **Defining the Needs**

Establishing the requirements for a weapon system is a function of the using command. In the case of bombers, ACC and Strat Comm will define the proper needs consistent with their developing missions. Through the final months of 1991, the air vehicles requirements office of headquarters SAC prepared long-range planning documents for the bomber force. SAC called these documents "bomber road maps" and designed them to put into focus the needs of the bomber fleet in terms of new equipment and weapons for the next 10 years. The road maps help document command requirements to be used as a basis for future mission need statements (MNS) and subsequent operational requirements documents (ORD). Once validated, the MNSs and ORDs generated by the using command define the legitimate future bomber needs.

Readers should not confuse the requirements found in the following paragraphs as a source document for bomber requirements; SAC wants readers to use the requirements listed below as substitutes for the extensive research and dedicated effort required to produce the bomber road maps. The next few paragraphs offer an overview of some of the possible major needs required to bring our current bomber force to the technological level necessary to remain viable in a conventional conflict. Since SAC procured these bombers primarily for nuclear warfare, it made certain that they required few modifications beyond those already planned (such as completing the defensive system on the B-1B) or needed to allow the aircraft to perform their nuclear missions. However, SAC realized that it needed to make major improvements for the conventional mission.<sup>21</sup> Modifications made to improve the

conventional capability also should enhance the capability of the aircraft to conduct its nuclear mission.

The offensive needs of our existing bomber force fall into three major categories: improved target destruction capability; improved command, control, and communications (and connectively); and improved onboard mission management. These categories are of course interrelated. For example, improvements in onboard mission planning would most likely require improved communication, and improved target destruction would require improved mission planning to locate and identify the targets. Central to each of these categories is the need to improve the overall computational capacity of avionics. If SAC simply were to add new targeting sensors or a mission-planning computer or new weapons, it would stand poised to overload the existing computer complex. Generally, however, improving the central computers consequently would provide at least the opportunity to improve any or all of these categories. More on this concept follows in chapter 3, but it is important to get an understanding of improved target destruction, improved communication, and improved onboard mission planning. Table 4 has an abbreviated list of aircraft needs.

**Table 4**

**Bomber Needs for Conventional Warfare**

**IMPROVED TARGET DESTRUCTION**

- Automated search and target identification
- Improved weapons integration capability
- Full GPS integration
- Improved radar resolution and/or additional sensors

**IMPROVED COMMUNICATIONS**

- InterAircraft data-link capability
- Space systems and headquarters data link
- Improved joint service interoperability

**IMPROVED ONBOARD MISSION MANAGEMENT**

- Instant In-flight replanning; fuel efficiency, threat avoidance, spike management
- Sensor management
- Data recording for recon and damage assessment
- In-flight maintenance

**Source:** The author.

**Improved Target Destruction.** The desert operation clearly demonstrated a capacity for the Air Force to conduct precise target attack, but it also demonstrated that the precision required could not always be achieved. Cloud cover significantly interfered with the laser-guided weapons in the early days of the war, and finding and destroying the mobile Scud missiles proved formidable. Also, during the Gulf War, the allied forces quickly gained air superiority. Without air superiority, the Air Force would not have had the

loiter time required to deliver many of our modern smart weapons. For wars of the future, fighters and bombers must have the capacity to see through the clouds or fog, find a mobile or hidden target and then destroy it completely and quickly.

Some of the targets of future wars will not differ from those of the past, when dumb bombs may cheaply and adequately fill the need. However, it is equally likely that future wars will require precise attack against increasingly elusive targets. For these targets, bombers will need a much-improved ability to search, locate, identify, and destroy. Two ways currently exist to search and locate a potential target. One way is to commit an off-board system to do this task, then pass the information to the bomber for final identification and destruction. The other method tasks the bomber itself to do the job. If an off-board system fills this requirement, then the bomber must have a method to get this intelligence data in the aircraft in a timely manner and in a form readily usable by the avionics computers.

If the bomber searches, locates, identifies, and destroys autonomously, it needs several major systems improvements. First, to search a wide area of the battlefield, the bomber's computers must handle complex software search algorithms. The algorithms would automatically direct a sensor (or sensors) through search patterns and, after identifying potential targets, it would present these to the operator or another computer for final identification. Second, the aircraft must have an improved target identification sensor. This addition may involve simply an improvement to the resolution of the existing ground-mapping radar or the addition of a new sensor to be used alone or to be fused with the radar. Third, if the weapons require terminal guidance, the bomber would need an improved capability for this task. Current bomber systems have little capacity for laser or radar final guidance. Finally, these three bombers should have the capability to receive and pass global positioning system (GPS) data to the weapons. In other words, GPS should be totally integrated into the bomber's avionics.

In reality, the potential for a third method of improved target destruction does exist. This method involves a shift from smart weapons to brilliant weapons. Here the bomber would simply bring the weapon into the area and let it fly on its own to search, locate, identify, and destroy. No doubt, we are rapidly moving in a direction where our weapons technology can execute attack against some difficult targets. However, such weapons would most likely be expensive and perhaps more importantly, unrecallable. Nevertheless, the bombers' computer systems would require upgrading whether or not SAC improves the capability of bombers or the weapons have to handle a task it did not envision during procurement.

**Improved Communications.** No doubt, good communication holds the key to success in any human endeavor. Warfare is not an exception; in fact, warfare is probably an area where poor communication almost always leads to catastrophic failures. Advancements in technology and weaponry allow accurate and timely communication to become even more essential. For the bomber to keep pace, it must have an improved communication system.

The bomber needs communication improvements that go beyond simply adding better radios, although this addition serves as a good starting point. The most vital improvement needed is an ability to share computer data between aircraft and between aircraft and ground stations. In other words, a bomber must have the capability to link data between aircraft (including aircraft to weapon) and to uplink or downlink between aircraft, space systems, and ground control.

In the dynamic environment of a conventional war, target information must be passed quickly and completely to the aircraft. During Operation Desert Storm, the B-52s took off from bases which were a great distance from the target areas, and they often had several mission and target changes before the actual bomb runs. The mission changes came by radio or Air Force satellite communications (AFSATCOM), but navigators had to load them into the computers manually. These frequent mission/target changes caused the B-52s to miss their targets on several occasions. For the next war, the bombers must have the capability to use a modem to load data directly to the central computers, thereby reducing time, errors, and work load on the navigators.

The third area where improvements in communication is needed is in the area of interoperability between the services. Our scaled-down military requires greater cooperation between the various military components. These components currently cannot communicate and share data vital to the conduct of war. As a minimum, aircraft must be able to communicate with the Army, Navy, and Marine Corps. Ultimately, a bomber should be able to transmit targeting data instantly.

**Onboard Mission Management.** Thanks to rapid improvements in the speed and computational capability of microcomputers, real-time onboard mission planning (or replanning) is now a reality. Many mission-planning tasks performed during preflight are extremely burdensome or impossible to reaccomplish in flight. The bombers were built generally for a nuclear mission that underwent few in-flight changes after launching. Conventional warfare, however, is much more dynamic and provides ample opportunity to make major mission changes that necessitate in-flight mission replanning. Bombers need a system that allows the computers to do what the navigator currently does during in-flight mission changes.

Ideally, an onboard mission-planning computer would do much more than simply crank out a new set of turn points and target coordinates. The mission-planning computer should manage the mission; that is, when replanning, it would account for fuel use by providing the most efficient flight path, avoid known threats identified from information that has been either stored or data-linked in, and manage the aircraft's orientation to reduce the aircraft's radar reflectivity. In addition, the onboard mission-planning computer should manage the sensors for target search, sensor fusion, and emission reduction. The computer also must have the capacity to store large quantities of geodetic data for more efficient, low-altitude, terrain-following operations. In short, the onboard mission manager, while in flight, must be capable of handling tasks normally done during preflight.

The potential of a mission manager computer exceeds the demands of onboard mission planning. For example, the mission manager could track aircraft systems, store information for postflight analysis, record and analyze equipment malfunctions as they occur, and suggest potential work-around solutions to the flight crew, while at the same time planning the best alternatives for continuing the mission. The computer also could store sensor data for reconnaissance and strike damage assessment. A true onboard mission management computer should perform most of the tasks that could overwhelm the bomber crew in a conventional war.

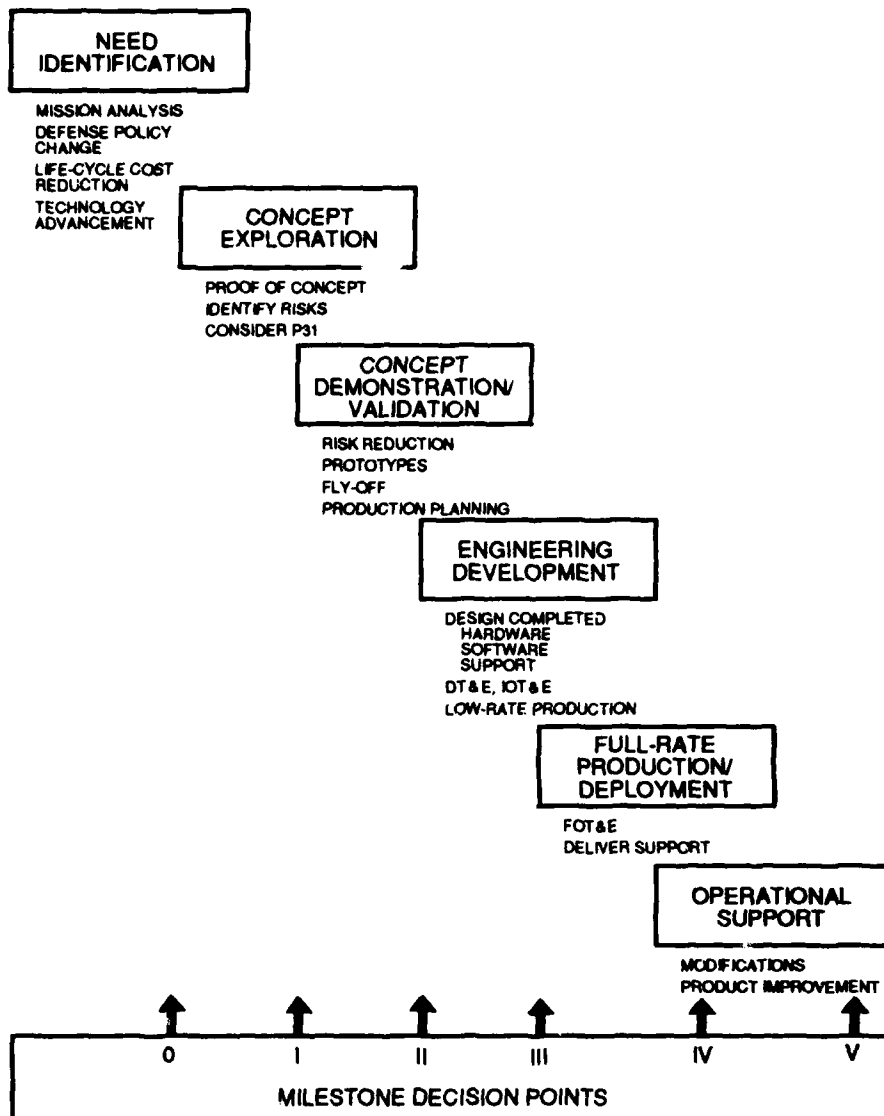
## **Fulfilling New Requirements**

One of the largest questions now facing SAC is how to fulfill the conventional needs of a bomber force without building a new aircraft. Once again SAC should turn to Dr Gray's principles for planning during times of uncertainty. Principle number six (see table 3) states that SAC should "play to American strengths," noting that Americans have excelled at substituting machines of all kinds for scarce or militarily inefficient manpower.<sup>22</sup> Similarly, just after Operation Desert Storm, General Butler, in an address to the Air Force Association, summarized one of the major reasons for SAC's successful air campaign in this war:

*Technology.* When it comes right down to it a lot of what happened here is that our electrons worked a whole lot better than his [Saddam Hussein's] electrons. In fact, when the chips were down, a lot of his electrons, like a lot of his soldiers, went on strike. But that didn't happen by accident. For years a fundamental tenet of the United States national military strategy has been that we substitute technology for manpower.<sup>23</sup>

Without a doubt the Gulf War will not be the last war in which the United States will fight. Therefore, to keep an advantage and to maintain the type of success the United States experienced in the Gulf War with scaled-down manning, SAC must continue to employ its technology fully by using that technology to meet the changing requirements of our weapons.

However, technology alone cannot solve all of the bomber's problems, nor does technology necessarily offer a low-cost solution to the problems that can be solved through the use of innovative technology insertions. In some cases if SAC merely changes procedures or tactics, the bomber may meet the required need. In other cases, however, SAC may find an adequate solution in a different weapon system. One must always keep in mind that acquiring a new system does not offer a quick solution. Figure 3 depicts a typical acquisition cycle. Proper acquisition requires careful planning and years of testing and building. In any event, the time has come to begin to prepare the bomber for its next use in war.



**Legend:**

- DT&E— Developmental Test and Evaluation
- FOT&E— Follow-on Test and Evaluation
- IOT&E— Initial Operational Test and Evaluation

**Source:** The author.

**Figure 3. Phases of a Major Acquisition Program**

## Notes

1. Maj Gen Robert M. Alexander, "A New Paradigm," white paper (14 January 1991), 1.
2. Ibid., 3.
3. Lee Kennett, *A History of Strategic Bombing* (Washington, D.C.: Library of Congress, 1982), 28.
4. *The United States Strategic Bombing Surveys (European War) (Pacific War)* (1945; reprint, Maxwell AFB, Ala.: Air University Press, 1987), 37-38.
5. Ibid., 119.
6. Gen T. Ross Milton, USAF, Retired, "Strategic Airpower: Retrospect and Prospect," *Strategic Review*, Spring 1991, 13.
7. Gen Curtis LeMay, "General LeMay Reflects on SAC," *Combat Crew*, October 1986, 9.
8. *Strategic Air Command and the Alert Program: A Brief History* (Offutt AFB, Nebr.: Office of the Historian, Headquarters SAC, 1988), 30.
9. Tom Vuriu, "Flexibility Key to LeMay's Value to Nation During Peace and War," *Air Force Times*, 9 March 1963, 1.
10. Secretary of Defense Dick Cheney, memorandum, subject: Unilateral Reduction of Nuclear Forces, 28 September 1991.
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12. "Air Force Restructure," white paper (Washington, D.C.: Department of the Air Force, September 1991), 5-6.
13. Ibid., 6.
14. Gen George Lee Butler, CINCSAC, testimony to the House Armed Services Committee, 20 February 1991, 3.
15. Ibid., 5.
16. Gen George Lee Butler, speech to National Press Club, Center for Defense Journalism, Washington, D.C., 27 September 1990.
17. Briefing, Headquarters SAC, Offutt AFB, Nebr., subject: Twin Triad, Spring 1991.
18. *The Air Force and U.S. National Security: Global Reach—Global Power*, white paper (Washington, D.C.: Department of the Air Force, June 1990).
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20. Dr Colin S. Gray, "Defense Planning for the Mystery Tour: Principles for Guidance in a Period of Nonlinear Change," *Airpower Journal*, Summer 1991, 18-26.
21. "Mission Need Statement (MNS) for an Adverse Weather Precision Strike Capability" (Draft), Headquarters SAC/XRHA, October 1991.
22. Gray, 18-26.
23. Gen George Lee Butler, CINCSAC, remarks to Air Force Association, Omaha, Nebr., 7 March 1991.

## **Chapter 2**

# **The Status of Bomber Technology**

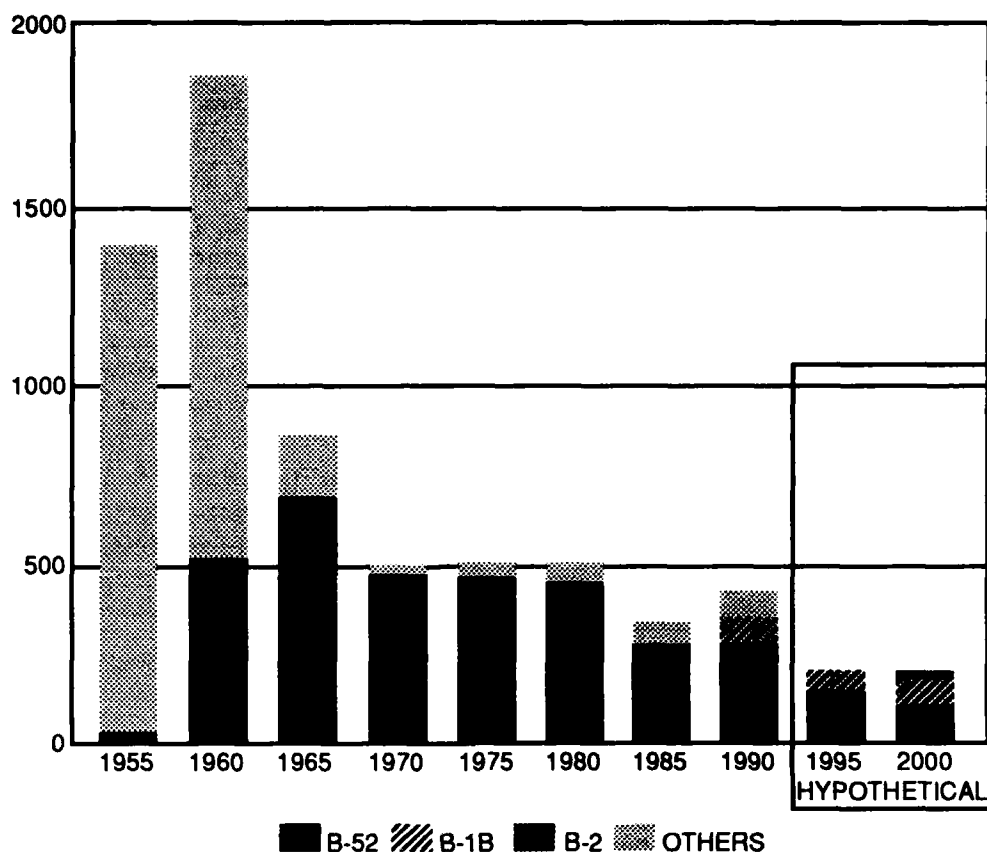
Before launching into a discussion of technology insertion concepts that fulfill the new needs of our bomber force, I must clarify SAC's current capabilities. The age of the bombers in the inventory covers a time span of 30-plus years, but, surprisingly, much commonality exists between the avionics technology of each year. Having a good understanding of this technology enables the reader to apply more expertly the technology insertion concepts outlined in the next chapter. That understanding also provides a better framework from which to assess the strengths and weaknesses of the total bomber force to manage assets better in the future.

## **Introduction to Bomber Technology**

The war-fighting power of America's bomber fleet has improved gradually. However, uninformed observers may disagree, particularly if they based their assessment of air power on numbers of aircraft. The composition of the SAC bomber force, in terms of the number and type of aircraft, has changed dynamically over the command's history. In 1946, when the command was formed, SAC controlled about 148 bombers—all were B-29 aircraft. By 1958 the number of bombers had increased to an all-time high of 1,947—mostly B-36, B-47, and B-52 bombers.<sup>1</sup> Figure 4 illustrates the rapid decline in the number of aircraft that began in the mid-1960s. Note that even the number of modern bombers (i.e., B-52 and B-1) declined.

The actual story of the enhanced war-fighting power of SAC bombers is not seen in numbers of aircraft, but in examining the technology change. The most obvious strategic bomber technology improvement began in 1949 with the introduction of the jet engine and the B-36. The jet engine provided a huge leap in aircraft range and payload performance. However, the real technology revolution came not with the jet engine, but with the introduction of new and increasingly sophisticated electronics or avionics. Just as the jet engine provided greater range and payload, modernized avionics provided a programming capability and an accurate delivery for a large number and variety of weapons.

In his book *Augustine's Laws*, Norman Augustine humorously illustrates the phenomenal growth in avionics. Law 14 states that, "After the year 2015, there will be no airplane crashes. There will be no takeoff either, because



Source: Norman Polmar and Timothy M. Laur, *Strategic Air Command: People, Aircraft, and Missiles*, 2d ed. (Baltimore, Md.: The Nautical and Aviation Publishing Company of America, 1990).

**Figure 4. Bomber Availability**

electronics will occupy 100 percent of every airplane's weight."<sup>2</sup> Augustine purposely exaggerated in this instance to make a point about the significant growth in avionics. Figure 5 shows the trend from which Augustine drew his law. Augustine's Law exists mainly for fun, but it does accurately depict the trend in avionics which has given us vastly improved war-fighting capacity. More specific to the bomber, he states:

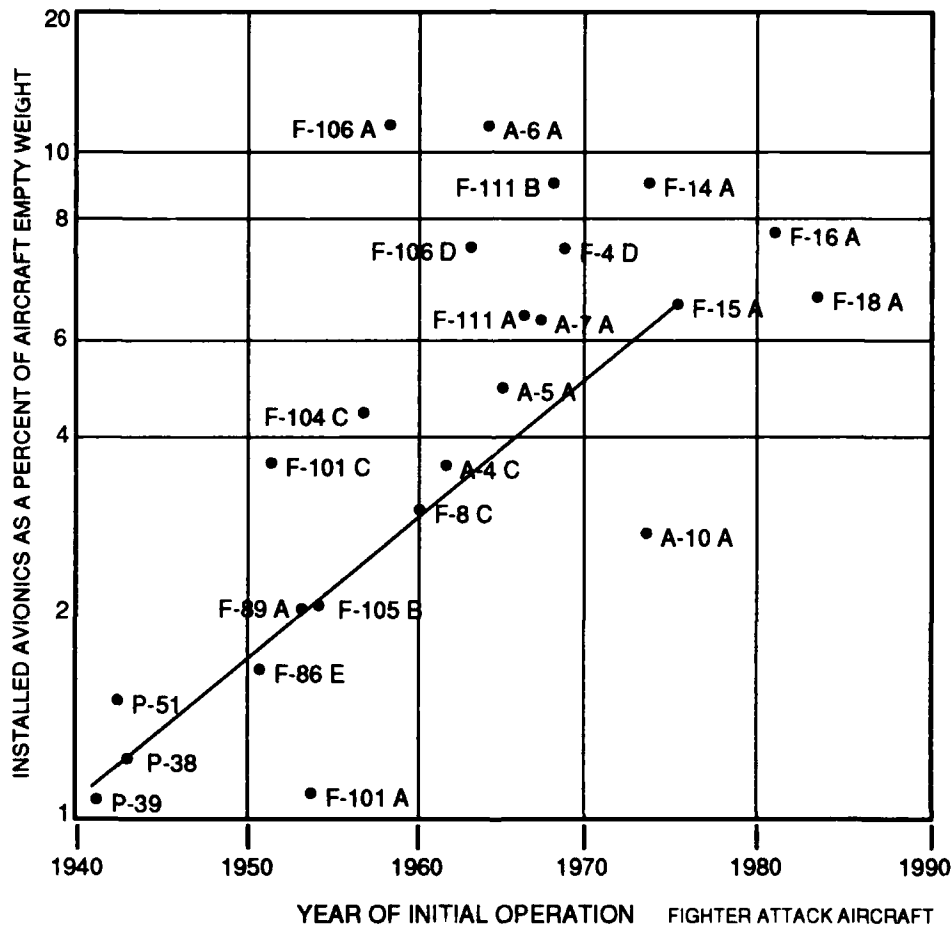
This trend is nowhere better represented than in the case of the military bomber aircraft. The World War II B-29 contained about 10,000 electronic component parts, the B-47 approximately 20,000, the B-52 50,000, and the B-58 nearly 100,000—or a factor of two each generation. But this rate of growth has been eclipsed by the B-1, which is packed with microcircuits containing as many active elements on a single quarter-inch chip as were carried in an entire B-58 a few years earlier.<sup>3</sup>

The exponential growth of avionics also established another premise: an inverse relationship exists between the number of crew members for each aircraft and the number for electronics. The B-52 requires six crew members; the B-1B, four; and the B-2, two. While these statistics may seem trite, they

weigh heavily on the work-load requirements of both the crew member and the machine, and work load embraces the most important consideration for defining the next avionics upgrades. But before we launch into a discussion of potential avionics upgrades (found in chap. 3), we need to examine the existing technology of our three modern bombers.

## The Enduring B-52 Stratofortress

The B-52 was, and in many respects still is, a marvel of technology. When one considers the time frame of its initial design and flight test in the early 1950s and then its monumental role in Operation Desert Storm 40 years later, one should have little doubt that the B-52 has had technological preeminence. Also note that the aircraft's development did not stop after its initial deployment.



Source: Norman R. Augustine, *Augustine's Laws* (New York: Penguin Books, 1986).

Figure 5. The Growth of Avionics

## **Aircraft Overview**

Over the years the B-52, envisioned as a "very high altitude" bomber, has adapted to many roles, including "very low altitude" bombing. The adaptations to new missions required much more than just changes in tactics; it required changes in technology (i.e., technology insertion). In the early 1960s these insertions included an improved B-52H jet engine for greater range; in the early 1970s, a new weapons computer for control of short range attack missiles (SRAM) and new electro-optical sensors; in the early 1980s, a completely new digitized offensive system; and in the early 1990s, additions and modifications to the aircraft's electronic countermeasures systems.<sup>4</sup>

The B-52 received more changes than just those items listed, but these modifications illustrate well the concept of adding flexibility through technology. New technologies gave the B-52 added capability, and the aircraft evolved to its current lethality (fig. 6). It features tremendous range and payload capacity, precise navigation, and superb control of modern conventional weapons. The aircraft is even designated to receive the triservice standoff attack missile (TSSAM), the most modern of conventional weapons.<sup>5</sup>

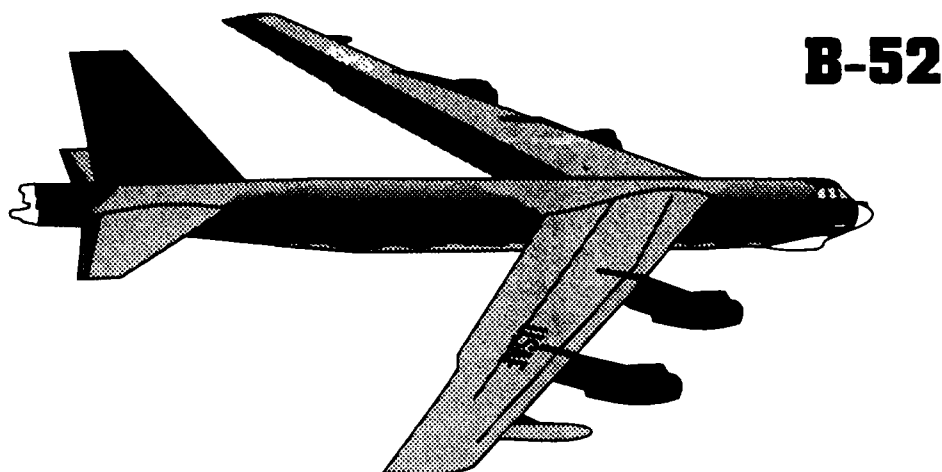
## **Avionics Architecture**

To fully appreciate how the B-52 has kept pace and how it has been able to integrate such weapons as TSSAM, we must examine the aircraft's avionics architecture to realize that the B-52 represents the last of its kind. That is to say, it is the only bomber still flying that was built as an aircraft, and not as an airframe to carry avionics. This means that the flight control, navigation, electronic countermeasures, weapons delivery, and other subsystems found on the B-52 differ from those found on the B-1 and the B-2. To further contrast, subsystems on the B-52 are independent, not integrated. The individual subsystems do work together, but they require increased crew member work load (or additional crew members).

The B-52 is an offensive weapon system. The center of its reason for being is its offensive avionics system (OAS), sometimes referred to as the central computer complex. The OAS relies on three computers that were designed with early 1980s technology computers.<sup>6</sup> Figure 7 describes the architecture of the OAS. The three central computers that appear in the center top block of figure 7 represent the foundation of what is commonly called a federated avionics complex. These computers, built by IBM, are pre-Mil-Std-1750A, 16-bit computers that run at about 600 thousand operations per second (600K OPS). Each has 128K of nonvolatile, random access memory (RAM) to store a flight control program (see the software overview section below). A Mil-Std-1553B data bus connects the central computers to each other and to the other subsystem within the offensive system.<sup>7</sup>

Through the 1553B data bus, the central computers reach out and control a navigation/offensive sensors subsystem, a weapons control/delivery subsystem, and a controls/displays subsystem. Within these subsystems is a variety of avionics computers. Most of these subsystems (line replaceable

With regard to the aircraft's overall performance (i.e., the ability to find the target), the navigation/offensive sensors subsystem holds probably the most important subsystem. To obtain precision navigation, the aircraft relies on sensory data from early 1980s technology, medium-accuracy, inertial navigation system (INS) and a standard ground-mapping radar which was



Wing span:	56.39 m (185 ft 0 in)
Length overall:	49.05 m (160 ft 10.9 in)
Height overall:	12.40 m (40 ft 8 in)
Wheel track (C/L of shock struts):	2.51 m (8 ft 3 in)
Wheelbase:	15.48 m (50 ft 3 in)

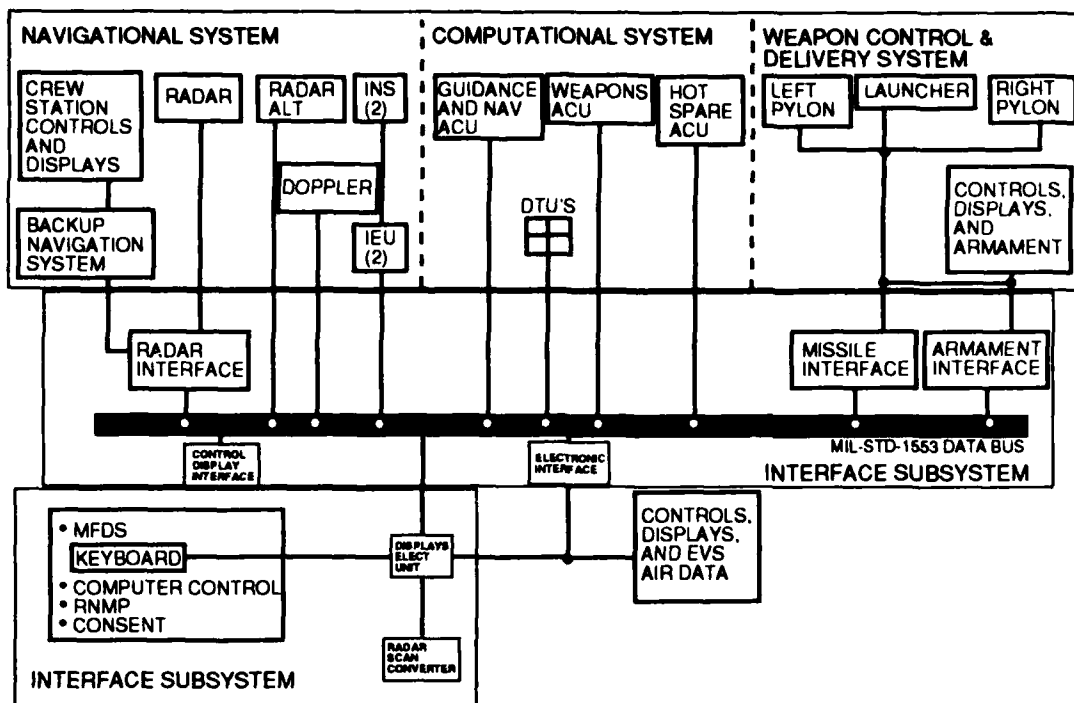
Wings, gross: .....371.6 m2 (4,000 sq ft)

**Max takeoff weight:** ..... **More than 221,350 kg (488,000 lb)**

Max level speed at high altitude: ..... Mach 0.90 (516 knots; 957 km/h; 595 mph)  
Cruising speed at high altitude: ..... Mach 0.77 (422 knots; 819 km/h; 509 mph)  
Penetration speed at low altitude: ..... Mach 0.53 to 0.55  
(352-365 knots; 652-676 km/h; 405-420 mph)

Service ceiling:	16,765 m (55,000 ft)
Takeoff run; G:	3,050 m (10,000 ft)
H:	2,900 m (9,500 ft)
Range with max fuel, without in-flight refueling:	
G:	More than 6,513 nm (12,070 km; 7,500 miles)
H:	More than 8,685 nm (16,093 km; 10,000 miles)

### Figure 6. B-52 Statistics



Source: Aircrew Flight Manual, T.O. 1B-52G-1-12.

**Figure 7. B-52 Avionics Architecture**

modernized in the mid-1980s. These systems are controlled through the OAS. The INS is generally aligned in flight and requires periodic adjustments from the ground-mapping radar. The radar also defines forward terrain for manually flown low-level flight. Some B-52s also are equipped with a global positioning system (GPS).<sup>8</sup> Navigation data is also available from a standard doppler radar and a radar altimeter. Additionally, the B-52 is equipped with 1970s-technology infrared and low-light television sensors, but these sensors are only partially integrated into the offensive system and are therefore of questionable value for the purpose of navigation and weapons delivery.

With regard to the B-52's primary mission of delivering offensive weapons, the most important subsystem is the weapons control/delivery. Weapons can be loaded either internally on racks or on a rotary launcher, or externally on under-wing pylons. To communicate with the weapons, especially today's smart weapons, some B-52s use a class-1C (full-up), late-1980s technology,

Mil-Std-1760A data bus. The B-52 is the only aircraft so equipped in the Air Force. With a class IA 1760A interface, the OAS can communicate with any imaginable (and some yet to be imagined) weapon; however, the weapon may require new software and hardware. Wiring from the 1760A weapon's interface can control both internal and external weapons.

Last of the three major OAS subsystems is the controls/displays subsystem. The two offensive navigators use several medium-resolution monochrome monitors for information display, and each has a numeric keyboard for selection of software switches and manual information input.<sup>9</sup> Also, many of the time-critical operator functions (such as weapons release inhibit) are located on a panel at the radar navigator's station. The controls/displays subsystem has the on/off switches for the entire offensive system and ground-mapping radar.

The three subsystems of the OAS discussed above are controlled by the central computers under common software. No single computer exists to control the aircraft's 1970/1980 defensive system, which should be named defensive systems because the aircraft actually contains a group of independent receivers and transmitters integrated manually by the electronic warfare officer. Each part of the defensive system has its own firmware.<sup>10</sup> A project is under way to integrate the various defensive systems, but not to integrate the defensive system with the offensive system in the fashion of the B-1B.

**Data Collection and Maintenance Diagnostics.** Because the B-52 is not software-intensive and because the avionics are not generally integrated, the aircraft has limited data collection and maintenance diagnostic capabilities. Pictures of the navigator's display can be recorded on a crude 35-mm film recorder, and offensive system parameters are recorded on a magnetic tape. Therefore, postflight mission analysis requires significant crew member documentation and explanations.

**Communications Equipment.** Avionics for communications include standard high- and ultrahigh-frequency radios for voice and an Air Force satellite communications (AFSATCOM) kit for long-range connectivity to headquarters. The AFSATCOM kit was added in the early 1980s and permits worldwide data reception and manually entered data transmission.<sup>11</sup> The AFSATCOM is not integrated into the offensive system to allow automatic transfer of targeting information.

## **Software Overview**

As mentioned above, the B-52 is not software-intensive in the sense of B-1B and F-16 generation aircraft. Nevertheless, the B-52 does employ significant amounts of software, particularly in offensive avionics (and firmware in the defensive system). Offensive software entered the aircraft with the introduction of the OAS in the early 1980s and has brought with it several major modifications to improve capabilities and operations.

The OAS contains approximately 200,000 lines of code written in the Jovial (J3B) software language.<sup>12</sup> This software was first declared operational in

December 1982 in conjunction with the deployment of the air launched cruise missile (ALCM).<sup>13</sup> This first operational software was designated "block 0," but because it had several significant flaws it was superseded within a year with block 1.<sup>14</sup> Block 1 continued as the operational software block until the late 1980s, when block 2 was fielded to support the common strategic rotary launcher and advanced cruise missile.

More significant, however, was the software modification required to alleviate a serious RAM problem in the central computers. The problem occurred because of the basic software architecture. The OAS software is divided into two major groups: nuclear and conventional. When the aircraft is first powered, the navigator will insert either a nuclear or a conventional program tape into a transfer unit and load the entire tape into the central computers, just as an IBM personal computer (PC) owner will load MS-DOS and a favorite program like *Wordstar*. However, unlike the IBM-PC, the B-52 loads into memory all the nuclear or conventional weapons the aircraft can carry. Compare this feat to the IBM-PC owner who tried to load simultaneously a word processor program, a graphics program, and a spreadsheet program. Needless to say, these programs quickly consumed available memory, and for the conventional weapons tape, there was insufficient memory to execute the potential weapons a B-52 could carry.

A creative solution reduced the problem of insufficient computer memory. The weapon overlays were removed from the flight software and placed on a different tape. Doing this required a major restructuring of the software but resulted in a much more efficient method of adding new weapons to the list of those capable of being carried by a B-52. The new software was named Integrated Conventional Stores Management System (ICSMS) and, along with other conventional systems improvements, began flight testing in February 1986.<sup>15</sup> We explore this concept of software architecture in greater detail in chapter 3.

### **Strengths and Weaknesses**

Without a doubt, and with repeatedly proven success, the B-52 is a magnificent bomber. In testimony before the House Armed Services Committee, General Butler, commander in chief of the Strategic Air Command, aptly summed up the importance of the B-52 when he argued that:

the venerable B-52 is a classic example of the versatility and adaptability of a large, long-range manned aircraft. It is a tribute to American technology and doctrinal flexibility.<sup>16</sup>

This aircraft brings to a war the capacity to haul a wide variety of weapons over a vast distance. For example, it can carry nuclear weapons more than 8,000 miles without refueling. These weapons include the B-61, B-83, short range attack missile (SRAM), ALCM, and advanced cruise missile (ACM); or, it can carry a huge array of conventional weapons, including Mk-82s, Harpoons, and Have Nap; and, in the future, TSSAMs. Even more, once the B-52 brings these weapons to the war, it accurately delivers them because the

basic design of the aircraft creates an unparalleled stable platform for accurate bombing.

Along with its flight characteristics, the 1980s technology avionics contribute to its lethality. Furthermore, especially with the new modifications to the offensive system software, the aircraft can adapt more quickly to other, or unplanned, weapons carriage. Finally, because of its range, cruise speed, stability, quality avionics, and loiter ability, the B-52 excels in sea surveillance, search and destroy, and many other missions.

Despite its many outstanding attributes, the B-52 has not escaped the attention of critics, who contend that its age makes the aircraft difficult to maintain and makes maintenance difficult. Its slow airspeed (attributable to 1960s technology) and its huge radar cross section make it extremely vulnerable to enemy attack.

Avionics don't help to overcome these criticisms; avionics have many problems of their own. For example, the same 1980s technology computers that provide flexibility have maintenance problems because manufacturers no longer provide the internal parts. Also, the avionics suffer because of the limited integration between systems. The offensive system is not integrated with the defensive system, and the GPS and infrared are only minimally integrated. The lack of integration, combined with a lack of excess computer capacity, results in limited growth potential and may cause the B-52's premature retirement.

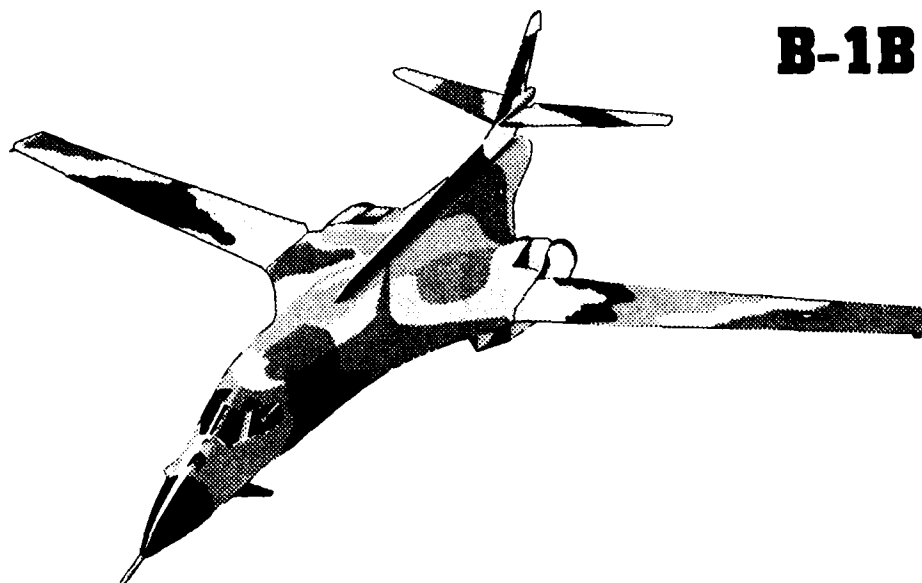
## **The Evolving B-1B Lancer**

The B-1B continues to be the most controversial and the most misunderstood aircraft ever brought into operation. The B-1B was born out of the ashes of the cancelled B-1 program, and with considerable contention. That it is called the Republican bomber indicates that the debate over its worthiness extends beyond aircraft capabilities. Observers who accepted the resurrection of the B-1 as a mistake failed to understand fully that the monumental and fundamental changes between the B-1 and B-1B created a totally new bomber that one day observers may regard as a bargain.

### **Aircraft Overview**

The total amount Congress allowed to design, manufacture, test, and deploy 100 B-1Bs was capped at \$20.5 billion (1989 dollars).<sup>17</sup> Designers fashioned the B-1B on the design of the B-1A, with basic changes in the aircraft to save money. The most important modifications included reducing the radar cross section to one-tenth of its previous size, changing the structure to allow for a 20 percent increase in maximum gross weight and adding 1980s technology avionics throughout the airframe.<sup>18</sup> The \$20.5 billion purchased a bomber that General Butler believes "is still the best operational bomber in the world today."<sup>19</sup>

Figure 8 outlines some of the features that make the B-1B such a worthy bomber. The aircraft has unmatched, low-level endurance speed. It cruises at .85 Mach (520 knots) at 200 feet in automatic terrain-following. Unlike other bombers, it can carry an unprecedented internal load of up to 75,000 pounds and an external load of an additional 59,000 pounds. The avionics of the B-1B are software- and computer-intensive and have a superb synthetic aperture radar, digital flight controls, and a totally integrated offensive and defensive suite.



#### DIMENSIONS, EXTERNAL:

Wing span; full spread:	41.67 m (136 ft 8 1/2 in)
Fully swept:	23.84 m (78 ft 2 1/2 in)
Length overall:	44.81 m (147 ft 0 in)
Height overall:	10.36 m (34 ft 0 in)
Wheel track (C/L of shock absorbers):	4.42 m (14 ft 0 in)
Wheelbase:	17.53 m (57 ft 6 in)

#### AREA:

Wings, gross:	Approx 181.2m <sup>2</sup> (1,950 sq ft)
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#### WEIGHT:

Weight empty, equipped:	87,090 kg (192,000 lb)
Max weapons load:	
Internal:	34,019 kg (75,000 lb)
External:	26,762 kg (59,000 lb)
Typical conventional weapons load:	29,030 kg (64,000 lb)
Max takeoff weight:	216,365 kg (477,000 lb)

#### PERFORMANCE (design):

Max level speed:	Approx Mach 1.25
Low-level penetration speed at	
approx 61 m (200 ft)	More than 521 knots (965 km/h; 600 mph)
Max unrefuelled range	Approx 6,475 nm (12,000 km; 7,455 miles)

Source: *Jane's World Combat Aircraft* (Alexandria, Va.: Jane's Info Group, 1988).

**Figure 8. B-1B Statistics**

However, like all other aircraft, the B-1B has developmental problems. Nearly all problems have been solved with the exception of the defensive system. Many observers believe the defensive system simply won't work, but this is not true even though the defensive system does not meet the Air Force's expectations—but, these expectations appeared before current technology. Despite its problems, the B-1B remains a formidable threat to all targets.

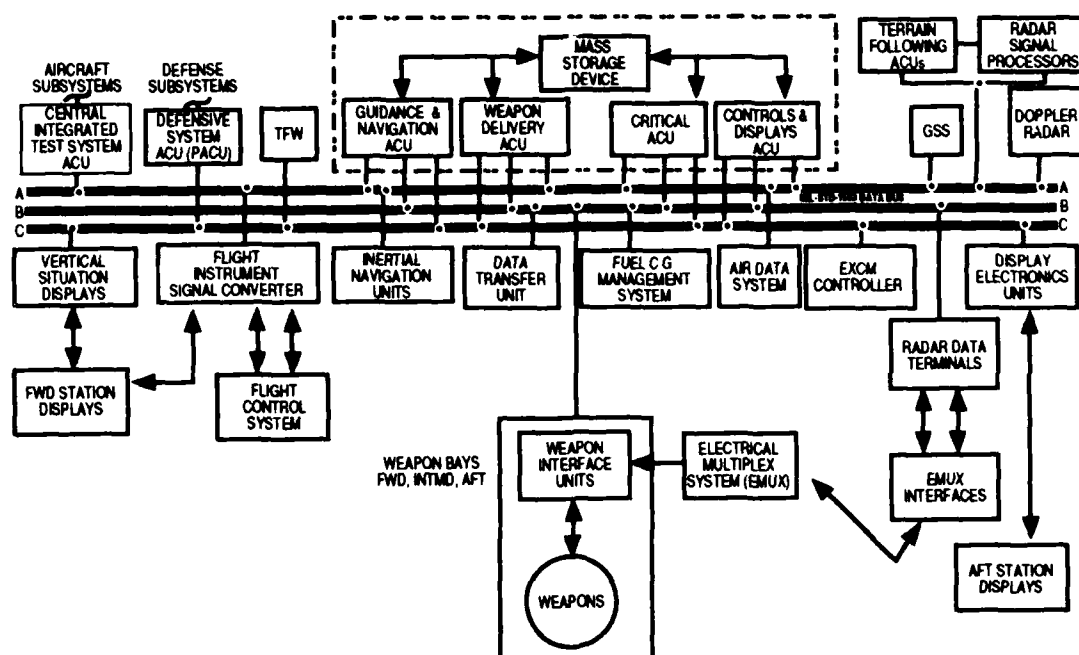
### **Avionics Architecture**

More than any other factor, the technology of the avionics determines the remarkable capabilities of the B-1B. Though not overly sophisticated, the B-1B is the world's first software-intensive bomber. To fly, the B-1 requires approximately 600,000 lines of software code.<sup>20</sup> The software-intensive attribute reduces the aircraft's basic weight, allows a variety of simultaneous activities, integrates all aircraft functions, and makes room for additional fuel or weapons. Virtually every command given to the aircraft is carried on the data bus and given priority by an electrical multiplex system. These systems are most susceptible to improvements through technology insertion, and the B-1 has an abundance of locations where technology insertion can provide extraordinary additional flexibility to adapt to new mission requirements. More data on these concepts appear in chapter 3, but let us now look at the technology of individual components of the B-1B avionics complex.

**The Central Avionics Complex.** The B-1B's avionics resemble a vastly expanded version of the B-52's offensive avionics system. Figure 9 depicts avionics architecture. Like the B-52, the system is built around a group of early 1980s technology, 16-bit, 128K RAM microprocessors that are referred to as the central complex. Also, like the B-52, the central complex communicates on a Mil-Std-1553B data bus. The center of figure 9 is roughly the same as the B-52 OAS. However, the similarities end at the center. Instead of confining itself to only offensive operations, the central complex passes along (across multiple data buses) many aircraft activities, including the center of gravity management, flight controls, pilot displays, defensive operations, terrain-following, and several other functions. In simplified terms, the central complex is the heart and brain of the aircraft; the radar is the eye; and the electrical multiplex system is the nervous system.

The B-1B operates eight IBM computers in the central complex. Four of them form the core (called the avionics control unit complex) and have 128K RAM each. These computers accept and execute the initial software load that defines what each computer will do. A mass storage unit (MSU) functions as a half-million word adjunct to the memories of the four control computers for nonvolatile storage of the entire offensive software load. Subservient to these computers are processors: one with 256K RAM for the defensive system software, two with 128K RAM for radar data processing for terrain-following, and one with a 256K RAM for processing central integrated test system data.

In figure 9 these computers are labeled ACU (avionic control unit) with the exception of the one 512K-mass storage unit. The MSU provides for major



Legend:  
 ACU — Avionics Control Unit  
 EMUX — Electrical Multiplex Unit  
 EXCM — Expendable Countermeasures  
 FWD — Forward  
 GSS — Gyro Stabilization Subsystem  
 INTMD — Intermediate  
 PACU — Preprocessor Avionics Control Unit  
 TFW — Tail Warning Function

Source: Rockwell International, briefing paper, 1991.

**Figure 9. B-1B Avionics Architecture**

improvements over the architecture of the B-52. The MSU functions as a simple hardware container for the basic operational flight software of the B-1B. Maintenance technicians load the MSU from the same data transfer units the B-52 employs. Whereas the B-52 computers take their software only from the data transfer cartridge magnetic tape, the B-1 computers use the MSU for nonvolatile, high-speed reloading of software. This dramatically increases the efficiency of loading and the ability of the MSU to recover from a catastrophic computer complex failure, and provides a quick-access container for holding infrequently used software routines.<sup>21</sup> Even though this architecture is an improvement, the technology of the central complex cannot be categorized as state of the art.

**The Offensive Radar System.** The B-1B does employ a state-of-the-art offensive radar. Its offensive radar system (ORS) provides for a phased array, synthetic aperture, electronically agile system. The ORS is a direct derivative of the F-16 radar and is capable of most of the same functions as the F-16, including low-emission, terrain-following, and high-resolution ground-mapping for navigation. The offensive system of the B-1B was designed

around a low observable antenna (LOA) radar philosophy. This operation may seem strange, but the radar operation drove the configuration of the other offensive systems to a considerable degree. The designers wanted to minimize the radio emissions of the B-1B, particularly at low level in enemy territory. This task was a difficult one, especially since the ORS must radiate to keep the aircraft safe while terrain-following. The designers resolved the problem of using LOA-phased array radar that flew terrain-following like no other aircraft by radiating a burst of energy, then analyzing the situation (in terms of terrain type, aircraft speed, and trajectory) to determine when the B-1B would require its next burst of energy.

The problem with this concept of operations, however, is that it uses the radar for more than just terrain avoidance; it uses radar for ground-mapping navigation updates and for final aiming on targets being bombed. To deal with this problem, designers created a complicated system of interleaving one function (such as terrain-following) with another function (such as bombing). This arrangement led to a saturation of the primary radar computer, the radar signal processor. More precisely, the Westinghouse Electric Corporation believes "the current B-1B AN/APQ-164 Radar Signal Processor (RSP) has reached its technology limit in terms of reliability, performance, and growth capability."<sup>22</sup> Because the radar is currently the only offensive sensor (eyes) of the aircraft, this technology limit presents a basic roadblock to the potential of the B-1B. Originally, the radar was designed as one of two offensive sensors, but a forward looking infrared (FLIR) sensor was eliminated to save money. However, the location or cavity where the FLIR was to be installed remains, and the wiring to support the addition of another offensive sensor was installed. A discussion of what technology could be placed in this location follows in chapter 3.

**The Navigation System.** The radar occupies only one part of the navigation subsystem of the central computer complex. This aircraft subsystem provides for two inertial navigation systems (INS) and for a standby input system for attitude and heading if the primary INS fails. The INSs are 1980s technology, standard accelerometer-type with high accuracy, but a documented low mean time between maintenance. High-quality INS performance is crucial. Without an operating INS, the aircraft cannot perform low-level, terrain-following, high-quality radar images or missile alignments. The alternate navigation system, referred to as a gyro stabilization subsystem (GSS), uses its 1970s technology as a spinning gyro for attitude and a magnetic flux for heading. The alternate system provides extremely poor performance, and the Air Force wants to replace it with a current-technology system.<sup>23</sup>

**The Defensive System.** Probably the most talked about, misunderstood, and controversial avionics system focuses on the defensive system of the B-1B. Ever since the B-1B became operational, the defensive system has come under fire from the print media and the government for its performance failures. Two popular misconceptions concerning the defensive system assert that it doesn't work in harmony with the offensive system and that it just doesn't work at all. These misconceptions are grounded in a long, public

debate over the actual system capabilities, and fortunately neither allegation is totally true.

Planners envisioned the defensive system of the B-1B as the answer to current and future threats to the aircraft. Theoretically, the system would detect and counter any threat at any time, but in reality, this ambitious concept was technologically unlikely when given the state of technology during the design phase, particularly in the context of the technology used on the rest of the avionics. The controls and displays portion of the defensive system is a subsystem of the central avionics complex.

After considerable flight testing, planners found flaws in this architecture which resulted mainly from the lack of the performance capacity of the defensive computer. But, because of the extensive integration, planners could do little without adversely impacting the rest of the avionics complex, which has worked well. Eventually, the Air Force arrived at a decision to leave the defensive architecture alone and to down-scope the system's performance requirements. In other words, they changed the defensive system from the logic of "counter all threats" to "counter only the most likely threats." So, the answer to the first misconception (that the defensive system just doesn't work) holds; the technology was not readily available to create a system to work as originally envisioned.

The second misconception (that the defensive system does not work in harmony with the offensive system) also has a "yes and no" answer. Yes, there are problems between these systems; but no, these problems do not significantly impact mission capability. To conduct a low-level bombing mission, the B-1 must transmit from at least the ground-mapping radar and the radar altimeter. Planners designed the defensive system to detect and counter emissions in the same frequency range as these offensive radars. To keep the two systems from interfering with each other, planners created a radio frequency signal management system (RFSMS). This system memorizes and then manages the emissions between the offensive and defensive systems to keep one from interfering in the mission of the other. The system works well until the threat environment becomes saturated (i.e., the system encounters many simultaneous threats to the aircraft). The manner in which the radar responds to this situation increases the possibility of radar failure. Once again, existing aircraft technology limits the solution to this problem.

**Weapons Delivery.** Another technological problem is the B-1's decreased capability to deliver conventional weapons. The B-1 has an equal, or perhaps superior, ability to navigate and to locate a target precisely, but it lacks the electronic interface to communicate with the B-52's diverse variety of conventional weapons. There are two reasons for this technology shortfall: (1) the designated primary mission of the B-1B narrowed the weapon carriage needs and (2) the technology standard for modern weapons was emerging simultaneously with the development of the B-1B. Both of these reasons no longer have validity, and the B-1B needs some state-of-the-art equipment before it can comply with modern standards.

The B-1B has the potential to adapt to as many types of weapons as the B-52, but it lacks a Mil-Std-1760A weapons interface, without which integration of additional high-technology weapons is severely restricted. Planners designed the B-1 to carry B-83, B-61, SRAM, and ALCM nuclear weapons and Mk-82 conventional weapons. These weapons, as well as most of the other weapons in the inventory, require only a Mil-Std-1553B interface. However, the Air Force has mandated the maximum use of Mil-Std-1760A for integration of future weapons.<sup>24</sup> This means that weapons-carrying aircraft will increasingly require the use of 1760 interface computers.

The B-1 was designed to receive a Mil-Std-1760A interface as part of the SRAM II integration program. Boeing developed a 1760A interface computer, commonly referred to as the ejected stores interface unit (ESIU), that would have replaced the existing 1553B weapons interface unit. Unfortunately, the fielding of the Boeing ESIU depended on deployment of SRAM II, but President George Bush cancelled the program in September 1991. So, until someone finds an alternative funding source, the B-1 must rely on the capabilities of the existing computer complex.

**Data Collection and Maintenance Diagnostics.** Because the B-1 is a software-intensive aircraft, it has a better capability to collect data for maintenance diagnostics than the B-52 does. The centerpiece of maintenance diagnostics, the Centrally Integrated Test System (CITS), monitors equipment health status data from around the aircraft and records this data on a magnetic tape. CITS also permits flight and maintenance crews to query this data for status of all system components down to the line replaceable unit level. However, CITS does not analyze or facilitate anything but manual intervention; the crew member must use the CITS information and acquired knowledge to correct malfunctions manually.

The technology of CITS parallels the rest of the central computer complex with one exception: a CITS expert parameter system (CEPS) is the first attempt on the B-1B to apply quasi-artificial intelligence in the form of a knowledge-based expert system. This statement means that a ground-based computer, which has the same knowledge of aircraft problems as a veteran maintenance chief, could systematically analyze an aircraft problem with the data collected by CITS. CEPS, which became operational in 1991, currently can analyze only offensive and defensive avionics problems. Although this system seeks to provide total aircraft analysis, the complete system has not been funded.

The B-1 also collects data for postflight analysis by using a 35-mm video recorder to capture radar images and a magnetic tape to record selected navigation parameters. The video recorder represents the same archaic technology found in the B-52. This system, which is vintage 1970, often produces poor, sometimes unusable, images and is difficult to maintain. The magnetic tape recorder also belongs to the B-52 genre and produces a useless or poor computer printout. Together, these two systems provide, at best, a weak link between the actual in-flight events and the needed information for proper postflight mission analysis.

**Communications Equipment.** The B-1 has nearly the same two-way communications equipment as the B-52. The aircraft has three radios (two UHF and one HF) and an Air Force satellite communications system.<sup>25</sup> Like the B-52, the B-1's AFSATCOM is not integrated into the avionics. The technology of these systems parallels the architecture of the early 1980s.

### **Software Overview**

Software, more than any other factor, controls the functions of the B-1B, the first software-intensive bomber. Modifiable software exists in nearly every system, and some of the software is a system unto itself. Several blocks of software abound for the offensive, defensive, radar, and countless software subroutines. This software not only allows the aircraft to conduct a mission; it also contributes to many of the difficult-to-detect system malfunctions.

The aircraft software falls into several major, but functionally related, blocks; and each block, though separate, depends on the others. Nearly all the software is written in the Jovial (J3B) language, the same language used by the B-52. The software is arranged into six general categories or blocks: offensive, defensive, radar, electrical multiplex, central integrated test system, and flight controls. These categories are loosely defined. For example, observers accurately refer to the offensive software as avionics flight software. This name provides some insight into its interdependence. Even though this software primarily controls the offensive avionics, it also controls the central computers, contains many of the controls and displays for the defensive system, and provides navigation information to the pilot displays. Grouping the software into major blocks with interdependent software relationships is the typical architecture for a software-intensive, federated avionics aircraft.

These relationships in the B-1B software mean that an error in one block may permeate the entire aircraft and cause multiple problems. Without a doubt, all software has errors. The nature of software complicates detection of these flaws. Since the errors are insidious, they occur only under either unlikely or difficult-to-repeat circumstances. Detection and correction of software errors consume much of the flight test time; contribute to maintenance down time when they are mistaken for hardware errors; and often result in large, unexpected expenses when designers must rewrite the software.

Writing software for the B-1 differs from writing software for the B-52 in the number of updates and the time lapses between the updates. The offensive system software provides a good instance to compare the two aircraft. Only three major blocks have been developed for the B-52's offensive system over a 10-year period, whereas four major blocks have been developed for the B-1B over a six-year period (with several revisions). The average time between B-1B offensive system software updates was generally less than two years. A two-year development time is typical of all six major blocks.

The reasons for developing new software vary, but they generally fall into one or both of two categories: either to correct deficiencies or to add a new capability. Figure 10 shows the development of the offensive software

discussed above. The predominate reason for successive releases of offensive software was to add new capabilities. For example, block 2.5 added the capability to launch short-range attack missiles, and block 4.5 added the capability to carry cruise missiles. But designers wrote block 2.5, the designated first operational block, with so many flaws that they issued block 3.5 to correct a variety of deficiencies, some of which were severe enough to cause flight restrictions.

It's important also to note that several minor software releases, or merges, occurred between the major blocks (see fig. 10). These merges were usually designed to correct minor deficiencies, but they did so at a major cost. For example, block 4.5, merge 3, which included 16 corrections and 24 enhancements, cost over \$15 million and took more than two years to develop.<sup>26</sup>

This extensive discussion of B-1B software may seem irrelevant to technology, but it has significance when one considers the crucial relationship between the software and the technological capabilities of the aircraft.

BLOCK II	DEVELOPMENT START	DELIVERY TO GOV'T
0	10-81	NOT DELIVERED
1.7 MERGE 2	3-13-85	8-16-85
2.0	10-10-83	NOT DELIVERED
2.0 MERGE 5	8-23-85	12-20-85
2.5	1-21-85	12-6-85
2.5 MERGE 6	2-7-86	2-26-87
3.5	10-86	NOT DELIVERED
3.5 MERGE 1		1-30-87
4.5	12-87	9-7-88
4.5 MERGE 1	11-88	12-1-89
4.5 MERGE 3	10-2-89	2-28-92
4.7	9-27-91	4-1-94 (PLANNED)

Source: Boeing Military Aircraft Corporation, briefing paper, June 1991.

**Figure 10. B-1B Nuclear Software Blocks**

Software makes the aircraft work; and computer speed and space available for the software set the limits on the software. In other words, adding software introduces new capabilities, but only to the point where the computers can store and efficiently execute the software code. The software is also related to technology, because it is nontangible and can be easily remolded to adapt to the technological need of the user. Therefore, software in a software-intensive aircraft, like the B-1, supports the foundation on which designers built the technological capabilities of the aircraft. The B-1B is built on a 1980s software foundation.

### **Strengths and Weaknesses**

The B-1B combines excellent aerodynamic characteristics with modern avionics to produce an aircraft with unexploited potentials. Without a doubt, the B-1 airframe delivers unparalleled low-level speed and excellent performance characteristics, and flight tests have proven the precise accuracy of weapons delivery. Testifying before the House Armed Services Committee on 20 March 1991, General Butler stated:

Even without the electronic countermeasures package, the B-1 is superior to the B-52. When you compute the capacity of an aircraft to penetrate, there is low altitude, because this takes away the majority of the [enemy] radar; low radar cross section because it compounds their tracking problem; [and] high speed, because it makes the intercept very difficult.<sup>27</sup>

Equally important, the B-1B represents a truly modern avionics aircraft; it is software- and computer-intense and functionally reliable. Additionally, the aircraft benefits from a state-of-the-art offensive radar sensor. Politics, fiscal constraints, and developmental problems have combined to obstruct the potential of the B-1.

The B-1B paints a picture of confusion in the minds of most Americans, including many within the Air Force community. Future planners have faced many problems in trying to overcome the many emotional statements made about this bomber. Perhaps the truth about the airplane's actual capabilities lies in a simple examination of the foundations on which it was built. These foundations include an airframe built to optimize high-speed, low-altitude flight, and expandable avionics to meet the ever-growing needs of the Air Force.

But this truth has another side: The airframe and avionics foundation were well suited for the nuclear mission at the expense of conventional employment. In his comments concerning the absence of the B-1 in Operation Desert Storm, General Butler told the Omaha area press, "We did not design, nor have we postured the B-1 to be, at this moment in time, a conventional bomber."<sup>28</sup> The B-1 was designed to make deep penetration missions, fly alone, and deliver nuclear weapons on a preplanned flight path.

Some observers may find it difficult to understand the difference between flying a nuclear profile rather than conventional profile. They may ask, "If you can do one type of mission, why not the other?" The answer lies in the

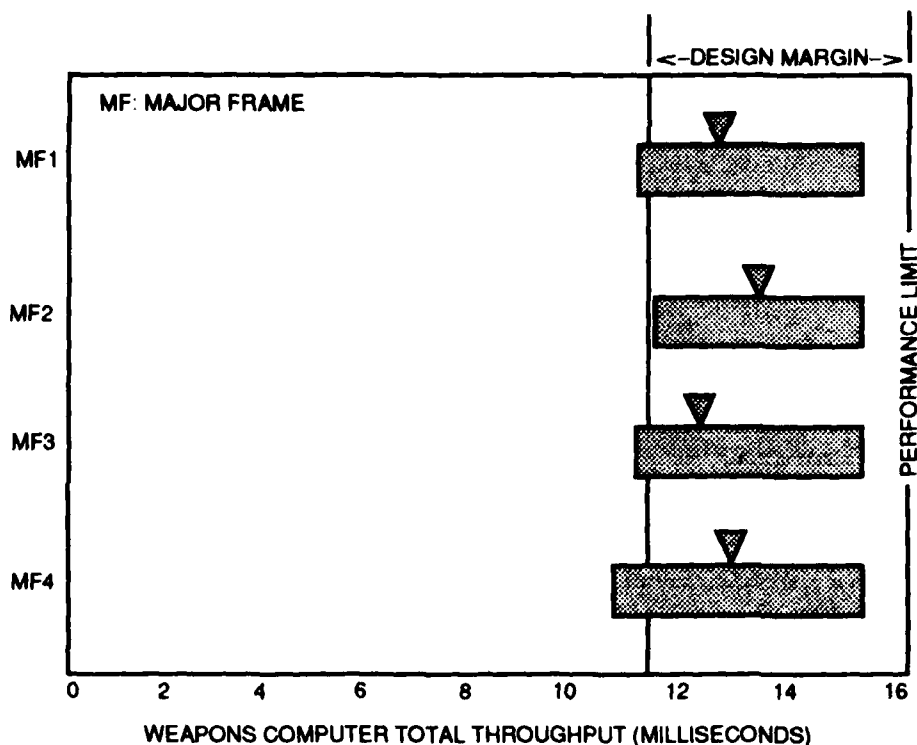
configuration and testing of the aircraft. Planners designed the B-1 for low-altitude, high-speed, terrain-following flight, and tested it against these conditions. As the Persian Gulf War demonstrated after the first day or so, low altitude was the wrong place to be. They also configured the B-1 to put nuclear weapons on alert and tested it on these conditions first. Conventional weapons testing began toward the end of the nuclear test phase. Even though the military procured the B-1 as a multirole bomber, they realized that the bomber's strength emphasized achieving the nuclear mission first.

What does this have to do with technology? The answer is a simple one. While the technological capacity of the B-1B is sufficient for the nuclear mission, it may not suffice for anything but the most unlikely conventional employment. The B-1 has demonstrated a capability to drop a load of 84 Mk-82, 500-pound, conventional dumb bombs from both high altitude (21,000 feet) and low altitude (200 feet). If someone tasked the aircraft to carry and guide a smart weapon, that person would discover that the aircraft would require additional computer capacity or a change in its computer configuration. A new sensor also might be required, further stressing the already overstrained computer complex.

Herein lies the ultimate problem. Even though the computer complex was designed for growth, the growth potential has been consumed. The B-1 uses its available memory to a point well above the recommended 70 percent margin.<sup>29</sup> However, a bigger problem is throughput (i.e., the speed at which the computers process data). Figure 11 shows the throughput of the central avionics computers. Adding more memory, which is still possible, may exacerbate the throughput. Adding new capability, like adding advanced weapons or a new sensor, may push the computer complex over the edge of the throughput cliff, thereby causing frequent and catastrophic computer failures. Manipulation of the software and the computer complex through technology insertion can solve this problem. We explore these topics in greater detail in chapter 3.

## **Genesis of the B-2**

Long held as one of the biggest secrets of American military technology, the B-2A is out of its closet, revealing a marvel of modern engineering. By using computer-aided design and manufacturing techniques, the Northrop Corporation finally made a flying wing, the cleanest aerodynamic shape, fly. But it's not just another version of the flying wing. Northrop applied the stealth concept in this aircraft to the nth degree. By a combination of composite material and clever designing, the aircraft will be hardly detectable by a searching tracker. The aircraft also is a marvel from an avionics perspective. The suite of the B-2 avionics is the largest one ever built. As the B-1B is an expanded version of the B-52, the B-2A offers an expanded version of the B-1B.



Source: Boeing Military Aircraft Corporation, briefing paper, June 1991.

**Figure 11. B-1B Computer Throughput Performance**

### **Aircraft Overview**

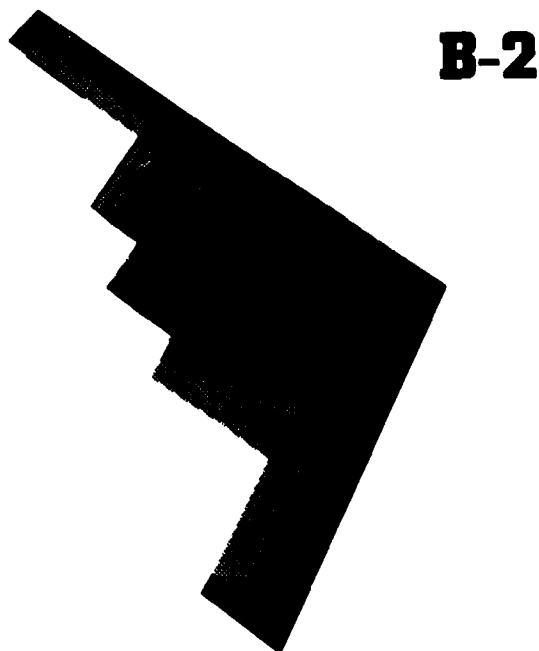
Computers make the B-2A fly, and when combined with the B-2A's unique airframe, they produce impressive flight performance characteristics. Figure 12 illustrates some of these attributes. Particularly noteworthy are the altitude envelope and range performances. The B-2 also can carry a weapons load of over 40,000 pounds in its two huge bomb bays, and like the B-52, it comes complete with a Mil-Std-1760A weapons interface computer for communication with modern weapons. Currently, the aircraft has the capacity to carry B-61, B-83, and SRAM nuclear weapons; Mk-82, CBU-87, and M-117 conventional weapons; and IGK/GPM Mk-84 precision conventional weapons.

The first B-2A was rolled out on 22 November 1988 and flew its first flight on 17 July 1989.<sup>30</sup> Congress has funded the continued development of the B-2 on a year-by-year basis, with each year presenting a significant risk that the next year will go unfunded. So far, 15 B-2s are under various stages of completion, and the first six B-2s will stay at Edwards Air Force Base, California, for long-term testing.

### **Avionics Architecture**

The B-2's life and the lives of its crew members hinge on complex avionics computers and an immense collection of software routines. According to Northrop, the B-2 is a highly integrated, software-intensive system,

containing 226 processors (computers), 69 operational flight (software) programs, 14 1553B multiplex data buses, 27 subcontractors that deliver software, 113 processor-to-processor interfaces, and 3,500 multiplex bus messages.<sup>31</sup> Searching the aircraft industry yields nothing like this vast avionics complex. Without these avionics the airplane will not fly.



## B-2

### ARMAMENT:

Two (2) side-by-side weapons bays  
Boeing advanced applications rotary launcher in each bay,  
or conventional weapons bomb racks in each bay

### NUCLEAR:

B-61 gravity bomb (16)  
B-83 gravity bomb (16)

### CONVENTIONAL:

Mk-82: 500-lb GP bomb (80)  
CBU-87: 1,000-lb CBU dispenser (36)  
M-117: 750-lb GP bomb (36)

### WEIGHT:

Empty: ..... <170,000 lbs  
Payload: ..... 40,000 lbs  
Fuel capacity: ..... >160,000 lbs  
Takeoff weight: ..... 376,000 lbs

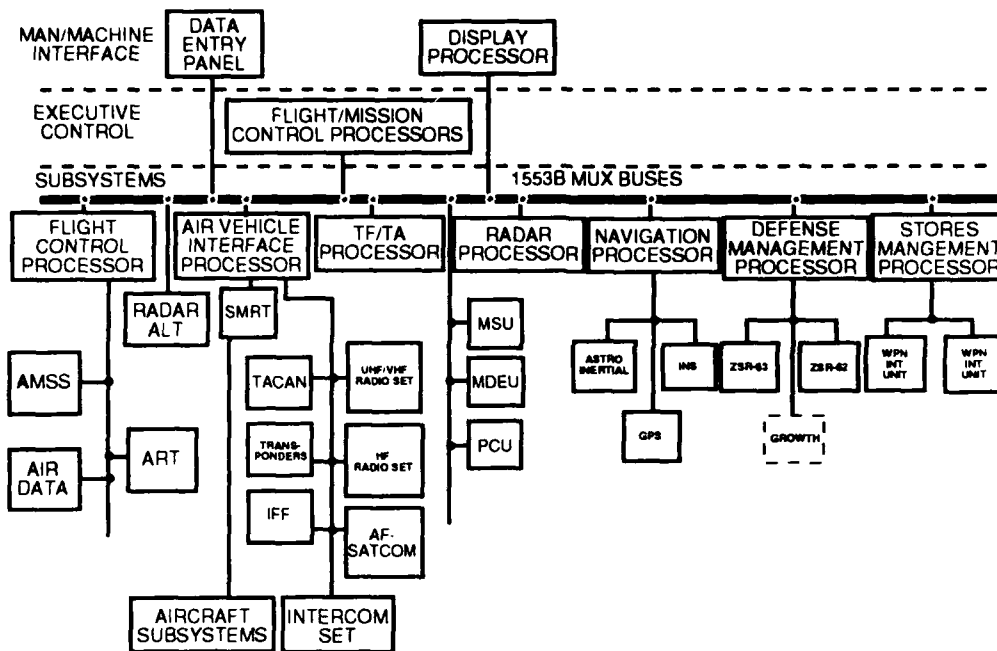
### PERFORMANCE:

Penetration speed: ..... 0.75 Mach  
Altitude: ..... Low altitude to 50,000 ft  
Range: ..... 6,700 NM all high altitude, unrefueled

Source: *Jane's All The World's Aircraft 1990-91* (Alexandria, Va.: Jane's Info Group, 1990).

**Figure 12. B-2 Statistics**

Interestingly, however, the B-2's avionics complex resembles the B-1B in architecture, and its hardware and software share a commonality also with the B-1B. Essentially, the technology of the B-1B and the B-2A represent the same vintage. Figure 13 describes the avionics complex. The B-2 avionics architecture has a federated hierarchical design, meaning that such various functions as navigation and weapons delivery are allocated to dedicated hardware and software subsystems. Thirteen avionics control units (computers) exist for each aircraft, which, like the B-1, are 16-bit and have Mil-Std-1750A architecture and a throughput of about one million instructions per second. Unlike the central computers on the B-1, the central computers on the B-1B have 256K RAM and are built by Sperry rather than IBM. These closed architecture computers comprise the foundation of all aircraft functions.



Legend:

ALT—Altimeter  
 AMSS—Altitude Motion Sensor Subsystem  
 ART—Actuator Remote Terminal  
 GPS—Global Positioning System  
 HF—High Frequency  
 IFF—Identification Friend or Foe  
 INS—Inertial Navigation System  
 INT—Internal  
 MDEU—Mission Data Entry Unit  
 MSU—Mass Storage Unit  
 MUX—Multiplex  
 PCU—Power Control Units  
 SMRT—Status Monitoring Remote Terminal  
 TACAN—Tactical Air Navigation System  
 TF/TA—Terrain-Following/Terrain-Avoidance  
 UHF—Ultrahigh Frequency  
 VHF—Very High Frequency  
 WPN—Weapon

Source: Northrop Corporation, briefing paper, 1991.

Figure 13. B-2 Avionics Architecture

From this foundation the central computers reach out across three Mil-Std-1553B data buses to control navigation, sensors, defense, offense, flight controls, displays, and flight management. Other than flight management, which is onboard flight planning, the functional layout of the B-2 is similar to the layout of the B-1. Also similar is the use of a low probability of intercept and a synthetic aperture radar. Westinghouse Electric Corporation built the radar for the B-1, and Hughes Aircraft built the B-2's radar, but the concept of operation for both bombers is the same. Because of its unique airframe, the B-2 has two ground-mapping radar antennas which feed data to an F-18-like radar signal processor and other radar units similar to those used on the F-15. Aircraft operators rely on radar for terrain-following, ground and air mapping, sea surveillance, and weapons delivery. For navigation, the B-2 has three major inputs other than the radar: pure inertial, astroinertial, and a global positioning system. These systems allow the B-2 to navigate precisely, and autonomously, to any location in the world. And, the navigation system, combined with the advance ground-mapping radar, permits accurate delivery of the B-2's weapons. For postflight maintenance, the B-2 has an onboard fault recorder. To defend itself, the B-2 uses ZSR-62 and ZSR-63 systems, both managed by a defensive computer.

**Communications Equipment.** Like the other bombers described in this report, the B-2 has a complete set of communications equipment. The aircraft has the standard voice communications radios: two UHF and one HF. The B-2 also has one AFSATCOM/MILSTAR UHF.

### **Software Overview**

The B-2 is a software colossus with over three million lines of codes required to execute its mission. Little data has been published on the B-2's software. It is understood, however, that the development of this much software is unprecedented. Development of the B-1's software, which is one-fifth the size of the B-2's, began in 1982 and matured with the delivery of block 4.5 in 1990. B-2 planners began to develop software in 1984, and they expect to complete full-scale development of the mission avionics software in 1993. This is a monumental task.

As mentioned above, 69 operational flight programs, written by 27 subcontractors, help to guide the B-2. Of these 69 programs, 47 of them guide the navigation and radar facets of avionics systems, 11 steer the flight controls, and 11 handle various air vehicle subsystems.<sup>32</sup> Details about the architecture of the B-2 software are classified. However, one detail that may provide an avenue for future exploitation: designers write all software in the common Mil-Std-1589 Jovial (J73) high-order language, just as they wrote software for the B-52 and the B-1B.

### **Strengths and Weaknesses**

The strength of the B-2 lies in the premise on which designers built the aircraft stealth. The B-2 doesn't fly faster or higher or with any greater

precision than the other two bombers, but when it does fly, it flies where it wants and without fear of the enemy. Well-known novelist Tom Clancy ably summarized what the technology of the B-2 means:

What stealth does is invalidate the weapons behind which some world leaders might be encouraged to hide with impunity. In simple terms, the B-2 bomber, with its range, payload and relative invulnerability, offers the same power as nuclear weapons, but with the added precision that makes its use politically possible. Its remarkable capabilities allow a strategic platform to be employed in a tactical mode, but with strategic effects. It is, in fact, a nightmare come to life for any tin-pot despot who has been able to purchase SAMs for cash from any of several willing markets. The stealth bomber for the first time offers the capability of applying the deterrence to people against whom deterrence has lost its value.<sup>33</sup>

There is a price to pay for this stealth characteristic—a sacrifice in aircraft maneuverability. The B-2 will never maneuver as the B-1 does, nor will it ever make supersonic dashes across the target areas. It is doubtful if technology will ever overcome this performance dilemma, but as long as the enemy's technology doesn't overcome the B-2's stealth attributes, invisibility will far outweigh a shortcoming in maneuverability.

The avionics of the B-2 provide a source of both strengths and weaknesses. The strengths of the avionics lie in their proven design, architecture, and software that they share with the other bombers. Another strength focuses on their high-quality, ground-mapping radar system that rivals the capabilities of the B-1 radar. The B-2 avionics complex offers a vast system with many opportunities for creative exploitation to improve the aircraft's flexibility through insertion of new technology. And the value of having common architecture dictates that a concept may be equally good for the B-1 and the B-52. Multiple but similar aircraft avionics mean multiple sources of new and innovative systems improvement concepts.

Many good concepts will be needed before the B-2 reaches its full potential, for the weakness of the B-2's avionics technology is that it does not possess cosmic new electronics, but simply a good old reliable early 1980s-federated system. And like the B-52 and B-1, the system suffers from a lack of real growth potential. This lack of growth potential creates some significant limitations if, in our rapidly changing world, the B-2 is tasked with an unexpected complex mission. Indeed, because of the new requirements (outlined earlier in chapter 1), the B-2, like the B-1, could definitely benefit from technology insertion. Because of this commonality, we must consider some concepts that apply to all three of these magnificent and complementary bombers.

## **Commonality between Bombers**

Before proceeding to concepts of technology insertion and to help summarize this chapter, I want to highlight the major elements of commonality among the three bombers. Table 5 shows the common features of the B-52, B-1B, and B-2A. The important starting place is the basic

architecture of these avionics. Each bomber has similar avionics, with each new bomber being an expanded version of its predecessor. However, don't allow the simplicity of this table to mislead you. The individual boxes that make up these avionics systems are not the same. They are quite different. You should not expect a B-2's computer to be compatible with a B-1's.

For both software and hardware, commonality means that concepts, and not necessarily equipment, can be applied in one aircraft's system as well as in another aircraft. More importantly, if a concept results in a hardware or software system changing the function of the basic architecture, the concept may help to solve the avionics problems of all three bombers with one piece of technology insertion. Chapter 3 examines these ideas.

<b>Table 5</b> <b>Bomber Avionics Commonality</b>			
<b>ATTRIBUTE</b>	<b>B-52</b>	<b>B-1B</b>	<b>B-2A</b>
FEDERATED COMPUTER COMPLEX	X	X	X
1750 ARCHITECTURE			X
JOVIAL SOFTWARE	X	X	X
1553 DATA BUS	X	X	X
1760 DATA BUS	X		X
SYNTHETIC APERTURE RADAR		X	X
<b>Source:</b> The author.			

#### Notes

1. Norman Polmar and Timothy M. Laur, *Strategic Air Command: People, Aircraft, and Missiles*, 2d ed. (Baltimore, Md.: The Nautical and Aviation Publishing Company of America, 1990).
2. Norman R. Augustine, *Augustine's Laws* (New York: Penguin Books, 1986), 124.
3. Ibid., 125.
4. *Jane's World Combat Aircraft* (Alexandria, Va.: Jane's Info Group, 1988), 288–89.
5. *Leading Edge* 38, no. 7 (August 1991): 5.
6. USAF Series B-52G Aircrew Flight Manual T.O. 1B-52G-1-12, 1–143.
7. Ibid., 141–42.
8. *Jane's World Combat Aircraft*, 288.
9. Software switch is a common term used in software-intensive aircraft. Many functions have no actual buttons on panels but appear as options to select on multifunction displays (MFD) (monitors). A good example of a software switch is the bomb delivery mode switch. To switch the bomb delivery mode from a free-fall to a high-drag requires the navigator to select the free-fall option from a list of bomb functions on his MFD.
10. Firmware is a software program inserted into a nonvolatile memory chip. Users can erase this software by subjecting the memory chip to an erasing technique, usually ultraviolet light in the laboratory. An electronically erasable programmable read only memory (EEPROM) is a common example of firmware.
11. *Jane's World Combat Aircraft*, 289.

12. Bruce Amerman, Boeing Defense & Space Group, Military Airplanes Division, Seattle, Washington, n.d.
13. *Jane's World Combat Aircraft*, 289.
14. The Boeing convention for numbering software blocks can be confusing. Generally, they will number major blocks of software beginning with 0. A merge to the software, which is software not totally recompiled, will be numbered as a decimal to the major block (for example, 1.7). A merge can however be a major change to the software affecting a wide range of functions.
15. *Jane's World Combat Aircraft*, 290.
16. Gen G. Lee Butler, CINCSAC, testimony to the House Armed Services Committee, 20 March 1991.
17. U.S. General Accounting Office, *Strategic Bomber: B-1B Cost and Performance Remain Uncertain*, report to the chairmen of House and Senate Committees on Armed Services, February 1989, 2.
18. *Jane's World Combat Aircraft*, 390.
19. Butler testimony.
20. Robe Poage, Rockwell International, North American Aircraft, interview with author, November 1991.
21. The B-1 and B-52 employ different technologies to load the basic avionic computer programs from storage. It takes approximately two minutes to load each B-52 computer from the magnetic data transfer unit cartridge tape. In contrast, it takes only two seconds to load a B-1 computer from the mass storage device.
22. Westinghouse Electric Corporation, "VHSIC Advanced Radar Signal Processing (ARSP) Capability Study—Revision A," Service Engineering Report Item B001 DI-S-3601A, 26 April 1991 1.
23. Memo for record, Bill Roberson, Oklahoma City Air Logistics Center, B-1 Division, subject: Alternate B-1B Gyro Stabilization Subsystem (GSS) Evaluation, undated.
24. Memorandum for distribution, Brig Gen William E. Collins, SAF/AQX, subject: Mil-Std-1760A, Aircraft/Store Electrical Interconnection System; Implementation Policy, 29 January 1991.
25. USAF Series B-1B Aircraft Flight Manual T.O. 1B-1B-1-1, 345.
26. Technical order, Boeing Defense & Space Group, Military Airplanes Division, *Revised Engineering Assignments 91-B1A1-B017R1, 89-B1D2-B005R3, and 89-B1D1-B006R3 and ECP 400-0290A*, Contract F34601-89-C-0292, 30 April 1991.
27. Butler testimony.
28. Gen Lee Butler, CINCSAC, transcript of comments to the Omaha press after assuming command of SAC, January 1991, 5.
29. Defense Systems Management College, *Mission Critical Computer Resources Management Guide* (Fort Belvoir, Va.: Defense Systems Management College, Technical Management Department, September 1988), 12-9.
30. *Jane's All the World's Aircraft*, 81st ed., 1990-91 (Alexandria, Va.: Jane's Information Group, Inc., 1990), 472.
31. Briefing chart, Northrop Corporation, subject: Elect System, 4 June 1990.
32. Briefing, Northrop Corporation, subject: B-2 Avionics, 15 June 1990.
33. Tom Clancy, "The B-2 Bomber Will Pay Peace Dividends," *The Miami Herald*, 7 July 1991.

## **Chapter 3**

### **Concepts in Technology Insertion**

Technology is one of America's strengths. Since the Industrial Revolution, America has led the rest of the world in inventions and innovations that increased the productivity of the workplace. The military, perhaps more than any other sector of our society, reflects our propensity for using technology in this way. Indeed, throughout the cold war, the United States relied on technologically superior weapons to offset an apparent Soviet advantage in numbers. And Operation Desert Storm vividly demonstrated how properly applied, sophisticated machines could win a war with minimum collateral damage.

Using leading-edge technology does have drawbacks. First, and foremost, this technology tends to look for a high-tech solution to every problem, even when a simple solution is available. Related to this is the inclination to use new technology for technology's sake (i.e., the new-toy syndrome). This notion led Gen Ronald W. Yates, then commander of Air Force Systems Command, to remark, "All technology advocated must have a war-fighting improvement associated with it."<sup>1</sup> This simple statement implies past abuses, where new technology did not deliver an enhanced war-fighting capability.

Other problems related to using the latest technology include escalating development costs and a quickening pace of obsolescence. The billions of dollars needed to deliver the technology of a B-2 offers evidence of the skyrocketing development cost; in fact, home computer owners have felt the pain of quickening obsolescence when they realized the computer they just brought home from the store is already slower than the newest model. America needs to keep pace in a dangerous world of ever-expanding technology, but we are forced to reach deep into our pockets of technical innovations because of a rapidly shrinking defense budget. Therefore, we want to produce weapons as cheaply as possible and with enough flexibility to avoid early obsolescence.

### **Nontechnical Technology Insertion**

Although America will have to use every tool available to prevent premature obsolescence, one hope centers around the insertions of new technologies into existing weapon systems. Fortunately, past acquisitions have provided an opportunity to take advantage of technology insertion. Whether by accident or design, many of our existing weapons rely heavily on

software-intensive microelectronic computers. These computers are perfect candidates for manipulation through technology insertion.

This chapter does not attempt to give an in-depth technical description of a variety of technology opportunities for bombers. Instead, it offers a much more simplistic approach. In place of a detailed analysis of which microchips need replacement, this chapter discusses the concept of modifying various hardware; and in a similar manner, it distills general software concepts rather than an itemized list of poorly written software that needs modification. In other words, this chapter offers a top-level view of technology insertion, not an engineering description. However, at least one engineering expert has verified each concept. The expert presents each concept in a simple manner to keep it simple.

### **Today's Definition of Technology Insertion**

While technology insertion is indeed a simple concept, it may sound intimidating. One may ask, "What technology? Inserted into what?" This writer defines technology insertion as the positioning of a new or current technology assemblage into an existing system to improve the overall system's capabilities without replacing the entire system. In other words, technology insertion replaces parts of a system to make the system work better, not differently.

Reasons abound for performing technology insertion, probably the most common being the need to replace an old part that is difficult to maintain or is no longer manufactured. When this occurs, it makes sense to replace the old part with a more capable one. Technology insertion also compensates for a design deficiency in an existing system. Here, the insertion corrects the unexpected problem. Technology insertion occurs when systems, having reached their full growth limits, fall short of their required performance capacity.

One must understand that technology insertion varies dramatically in magnitude. That is to say, the size of the insertion may be a small part of a small system, a large part of a small system, a small part of a large system, or a large part of a large system. For example, the insertion assemblage may be as small as one microchip on a circuit card in an avionics computer, or it may be an entire avionics computer inserted in place of an older one. Also, the inserted part need not be a hardware component at all; it may be improved software inserted into existing software to improve capacity or efficiency. The magnitude of the insertion is irrelevant as long as the recipient system executes the same function better.

A real-world example should clarify any remaining questions about what technology insertion really means. In an article titled, "Adapting to Changing Mission Requirements," *Avionics Magazine* reported:

Retrofitting F-14A avionics is a good example of growth through technology insertion. The Tomcat has been in service since 1972, and yet the majority of over 400 aircraft in the Navy inventory have their original avionics. During the last ten years, Fairchild Defense has developed quick-reaction solutions to changing mission needs without the cost and risk of reworking the entire avionics suite. The Technology Improvement Program for the F-14A Fire Control Set (FCS) is an example of newer technology to enhance an aging system.<sup>2</sup>

In this example, the Navy replaced and repackaged obsolete components and circuit cards. In exchange for this technology insertion, the F-14 obtained improved safety, a fault collection capability, and a degraded mode assessment/degraded mode operation capability.<sup>3</sup> The F-14 needs these insertions to achieve the new bomber requirements outlined in chapter 1.

### **What Technology Insertion Means for Bombers**

As mentioned earlier, existing bombers are excellent candidates for technology insertions. The B-52, B-1B, and B-2A employ progressively increasing amounts of microcomputer hardware and software. Although these systems have not aged chronologically since construction, they have aged in comparison to state-of-the-art computer processing. Essentially, each bomber's central computers use early 1980s technology avionics computers with increasingly difficult-to-maintain internal components (due in part to decreasing suppliers). Furthermore, Jovial software no longer falls within standards under software acquisition regulations.<sup>4</sup> Nevertheless, these are superior computer systems.

To put this information in perspective, note that most 1992 consumers would not want to buy 1982 computer (8088) technology; instead, they would want to buy the latest technology, such as a 486. If they owned the older 8088, they would remember that it performed the original tasks well, but they would realize also that its performance falls short of the potential of the 486. Suppose this consumer had a choice of either throwing out his old computer and buying the new one, or inserting the new computer's technology into his old computer. What should the consumer do? One would initially guess that, if the price of buying the new computer was roughly the same as upgrading the old one, the consumer should buy the new one. But this routine rarely occurs, and more importantly, the purchaser must consider the collateral costs. What if the new computer required new software, extensive training, a new set of spare parts, and a collection of new manuals; while the upgraded computer required no (or little) additional support? In addition, what if the upgrade could be done without disrupting the existing operating system? The answer becomes obvious: the consumer should select technology insertion to upgrade the old computer (unless price prohibited). This is exactly what is available to the B-52, B-1, B-2, and many other Air Force aircraft.

Of course, this example overly simplifies the issue because bomber avionics systems are not just one computer, but they are a complexity of interconnected computers and remote terminals with intricate software. Nevertheless, whether one considers the avionics in whole or in part, many areas where technology insertion can boost performance and growth capacity do exist. Opportunities range from simple changes of existing software to complex modifications of the avionics hardware. Generally speaking, modifying the software is much less complex. This situation occurs because a software (or firmware) change rarely requires a hardware change, whereas a change in computer hardware almost always requires a software update.

With this rationale in mind, the next two sections explore first the software and then the hardware concepts for technology insertion in a loose order of difficulty of implementation. (Note: planners have not decided at this point to establish an order of merit to these concepts.)

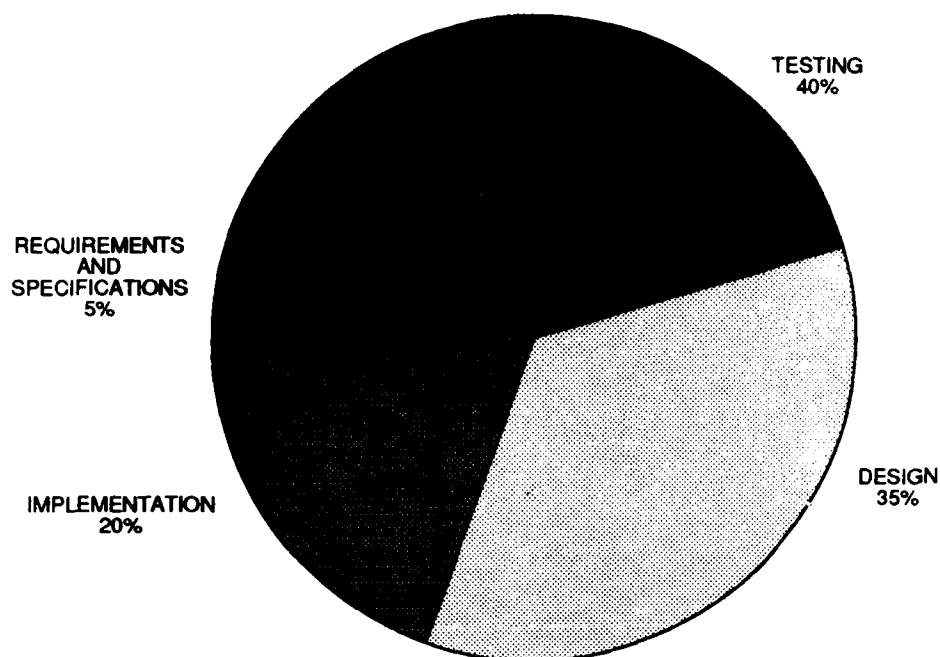
## **Software Opportunities for Bombers**

It has been said that we are moving to an era in which aircraft would resemble flying formations of avionics rather than airplanes. In many respects, we have reached this era, particularly as regards weapon systems like the B-2. Individuals from the traditional school of thought may long for the day when electronics were simple, when the stick was connected to control surfaces with cables and a flight computer was a circular slide rule. They view this tendency toward increasingly complex avionics as a liability and fear the results of trusting human lives to computers filled with unintelligible software. However, their view no longer predominates.

The number of computer-literate people grows daily, even among flight crews, who see computer-intense weapon systems not as a liability but as an unexploited asset. Before the advent of dense avionics, the only way to change the capabilities of the aircraft was to tear into the metal and then rebuild. As of this writing, planners can add new capabilities by tearing into nontangible software. What took months or even years to modify in complex metal shops can (theoretically) be done in days in a small software development lab.

The inherent characteristics of software provide ample opportunities to exploit it for improved weapons systems performance. To avoid a misunderstanding about what software actually is, the reader deserves a strict definition. Defense Systems Management College (DSMC) defines software as "the pre-defined set of instructions and associated data that are stored in a computer and are used to execute a function or functions."<sup>5</sup> The software instruction code comes from a flow diagram, then it is entered on a computer's hard drive. Like designing any written product, planners place a majority of their effort and expense on the creation (fig. 14). Once created, copies can be produced easily for as many computers as desired. Another characteristic of software is that the code is easily revised. Users can remove and replace large or small portions by using a revised code; or, they can insert a totally new code by adding a new function, providing sufficient memory remains. To summarize, users can exploit software to improve aircraft performance, because production doesn't require a huge factory; one can easily duplicate or modify the software for many systems.

Because of these software attributes, bombers can benefit greatly from a careful examination of the existing code to determine their strengths and weaknesses. When one finds a strength such as well-written (exceptionally efficient) software, the user should try to reuse it in similar systems. Likewise, a user should consider such actions as code optimization or simple



Source: Defense Systems Management College, briefing paper, Fort Belvoir, Va., 1991.

**Figure 14. Distribution of Effort In Software Development (Initial Development)**

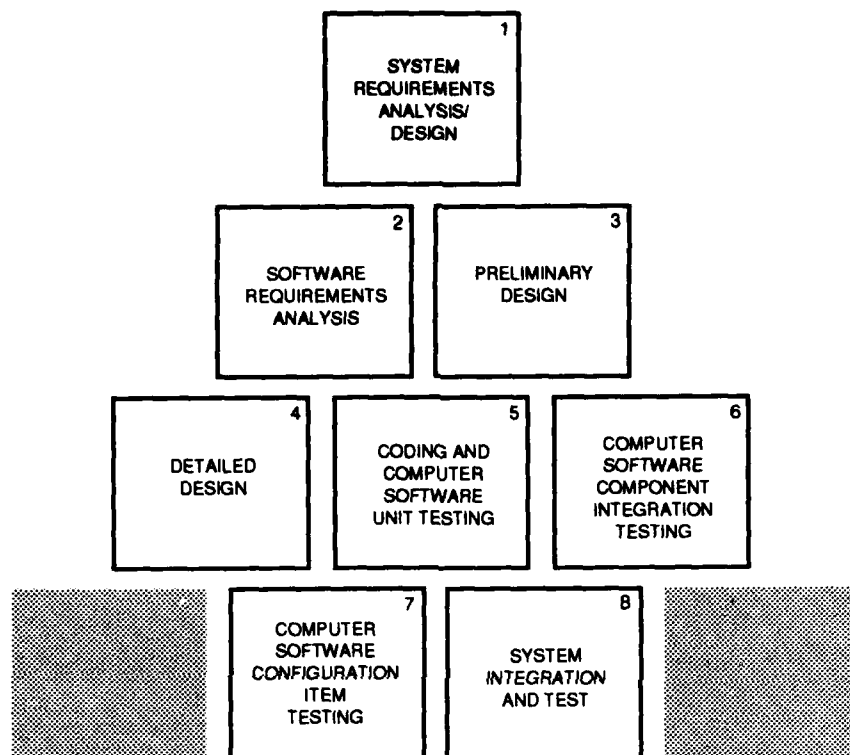
modifications to the architecture whenever he or she finds a weakness in the software. To take full advantage of the similarity and commonality of the three bombers, a user may want to reorient the code to a different form of processing. More about these concepts follows below; but first, a user needs to understand the process and limitations involved in developing a modern avionics software code.

### **Software Development**

Undertaking the development of high-quality, military application software is almost always a major effort. The standard time required to generate a new or modified software block is generally greater than 18 months from the time the requirement is identified until the flight software is ready. Figure 15 shows the DOD-STD-2167A eight-step process in software development.<sup>6</sup> And, the need to implement this process is rapidly increasing. In other words, as aircraft have become more computer-intensive and as the capacity of embedded computer technology improves, the need to produce software has increased. Robert Harris of Wright Laboratories states:

The amount of software in airborne weapon systems has been growing exponentially for the past three years and this growth is expected to continue at an even accelerated rate for the foreseeable future. Among the reasons for the phenomenon are the pervasive applications of digital technology, innovations in

computer science and engineering resulting in the migration of former hardware functions to software and the ease of implementing more complex and sophisticated capabilities in software.<sup>7</sup>

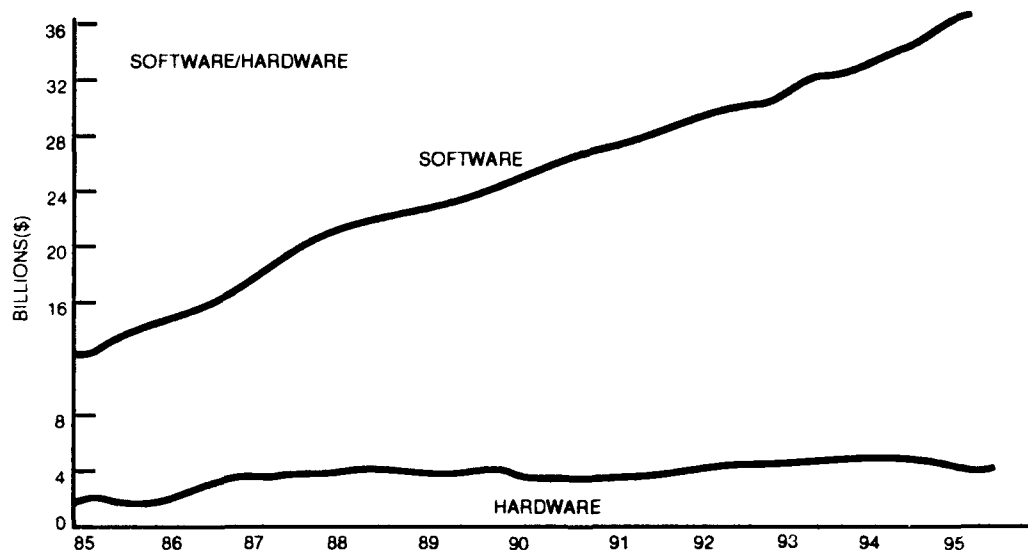


Source: DOD-STD-2167A, 1991.

**Figure 15. Software Development Process**

Using the cost of producing software as an indicator, figure 16 illustrates that software consumes an expanding amount of effort. It is unlikely that this expansion will cease in the near future.

At least two interrelated major problems result from the immense effort to produce ever-increasing amounts of Department of Defense (DOD) software. These problems include (1) inadequate procedures for developing quality software code and (2) a possible lack of national capacity to produce enough software to support the defense industry. Concerning the inadequate procedures issue, software engineer James McCord of the Wright Research and Development Center's avionics laboratory stated that "present software engineering and software development techniques have fallen short of meeting the demands of mission critical software development."<sup>8</sup> This problem creates a code that either does not meet the required need or is defective. Probably a greater concern from a national defense viewpoint is the lack of a national capacity to produce even flawed software. A report by the Carnegie Mellon University Software Engineering Institute states:



Source: Defense Systems Management College, briefing paper, Fort Belvoir, Va., 1991.

**Figure 16. DOD Embedded Computer Market**

Based on our preliminary findings, we conclude that the nation's software capacity problem is acute. Many of the conditions contributing to the problem are not new, and the magnitude of the problem appears to be increasing rapidly. To gain control of and improve the situation, Air Force leaders must be committed to bona fide changes in the way business is done among government, industry, and education establishments.<sup>9</sup>

The problems listed here should not alarm users, but it should warn users that any software technology insertion plan must provide for careful consideration of the availability of a software producer and the possibility that the software produced may have flaws.

The concept of producing or modifying large quantities of software code may not be hopeless. Several ongoing projects help to alleviate production problems. McClellan AFB Air Logistics Center is working on a project entitled "The Extendable Integration Support Environment," which has been designed to solve the supportability problems associated with the maintenance of embedded computer mission and system software. Through this effort, the software engineers believe they can achieve significant cost reduction in developing and maintaining weapon systems software.<sup>10</sup> Warner Robins AFB Air Logistics Center is developing a scheme for rapid emergency reprogramming of defensive system flight software. They want to complete an emergency software change within 72 hours from the time of receipt of the operation change requirement to initial distribution of the new software to the user.<sup>11</sup>

In addition to logistics center projects, other notable projects at the avionics labs at Wright-Patterson AFB include the advanced multipurpose support environment (AMPSE) project, the avionics fault-tolerant software (AFTS)

project, and the automated software validation (AutoVal) project. AMPSE uses modular simulation to test, verify, and validate automated software. If successful, AMPSE will reduce acquisition and maintenance costs, increase reliability and readiness, and facilitate resource sharing among various weapon systems. AFTS develops and demonstrates fault-tolerant techniques for advanced avionics software. This means that the software continues to operate in the presence of data and timing errors. Such software could reduce the burden to produce a flawless code. Finally, AutoVal automatically executes tests and records errors to support the validation of operational flight programs. AutoVal performs hours of complex tests without the intervention of a test engineer.<sup>12</sup> Gary T. Howell of the avionics lab claims, "It is estimated that AutoVal will be able to perform complex tests 100 times faster than a human test engineer, while avoiding human errors and giving time for more thorough testing."<sup>13</sup>

DOD controls the projects listed above. Of course, many civilian contractors have their own projects to improve the rapidity and accuracy involved in developing software, most of which is proprietary information. The important point to realize is that, like development of better and faster computers, the software industry refuses to stand still. Without these projects, a programmer would find it nearly impossible to implement software solutions like code optimization, reusability, architecture modifications, and object-oriented processing.

### **Code Optimization**

The first step toward improving the capabilities of bomber avionics software is to take a close look at what we have. Under changing requirements, designers built, rebuilt, and modified much of the software over many years. The net result produced software that is, at best, imperfect, and at worst, severely inefficient.

This occurs because of the quantity of software in relation to the acquisition process. Note from data in chapter 2 that the amount of software produced for each bomber has increased exponentially with each new bomber. Developing this software requires, at a minimum, several years. To move the aircraft along in the development process, designers have delivered the software piecemeal with initial blocks providing only basic capabilities and each subsequent block turning on more complex functions. Of course, designers have had a strict developmental plan for each software block so that the Air Force could anticipate weapon systems capabilities and so that subcontractors could plan associated deliveries. Two factors have interfered with this process: (1) users found flaws in the delivered software and realized that it needed rebuilding; and (2) users discerned that, because the acquisition had been spread out over several years, users requirements had changed, necessitating modifications. These anomalies, combined with the challenging nature of building complex integrated software, ultimately have caused flaws in most of the existing code.

A majority of the software imperfections fall into three categories: inefficient code, no-longer-needed code, and useless code. Inefficient code is software that has been built sloppily. In other words, the designer was more concerned about speed than about precision, or the designer may have been a poor designer. Regardless, unlike precisely written code, inefficient code usually requires more time or steps to execute the same task, which can quickly use up the limited memory and throughput. The same results occur when software contains no-longer-needed code. This type of code is software that was written for a function that either didn't work as expected or was deleted from the list of required tasks. There are many examples of this in each aircraft. For example, designers originally required the B-1B radar to perform a ground moving-target track function. This function failed to test properly and was later eliminated from the required task list. However, the ground moving-target track software module, though not used, still is part of the flight software, occupying valuable memory. Useless code resembles no-longer-needed code, except that useless code was never intended to execute a particular task. Most of the useless code became part of the software by accident, generally during a minor modification or a patching procedure. For one reason or another, code was left in a routine, but it is no longer accessed as part of any function. In other words, it's code that no longer serves any purpose, nor will it do so in the future. Inefficient code, no-longer-needed code, and useless code contribute synergistically to computation inefficiency.

Code optimization increases the efficiency of the existing software. When designers optimize the software, they remove no-longer-needed or useless code, and ensure that the code is written to execute tasks as efficiently as possible. Optimization increases available memory and improves throughput by reducing the number of lines of code a routine must read to carry out a function. Any software can benefit from a thorough review of its code. The software requirements planners asked Boeing to scrutinize code written for the B-1B, and the company found that it could optimize the software by up to 10 percent just by removing the no-longer-needed and useless code.<sup>14</sup> Optimizing the existing bomber code serves as a cost-effective way to improve capacity and enhance the likelihood of reusing this expensive software in other systems.

## **Reusability**

The reusability of software is rapidly moving to the forefront of most desired attributes. As the name implies, reusability allows software built for one weapon system to be reused, in whole or in part, in another system. In an ideal environment, where the software was written for a common weapons system, the same software would be adapted easily for use on another similar system. The significance of this quality should be obvious. In the ideal environment, users could simply write a common module of software for weapon system X and store a copy in a software library for use when

designers mate weapon system X with aircraft systems Y and Z and so on. Reusability of software then should dramatically decrease the need to produce new software when designers plan to mate an existing system repeatedly with different systems.

An example helps to illustrate the meaning of this routine. Suppose the B-52 had a program to integrate a new air-to-surface missile. Designers would need significant amounts of new software to integrate this missile into the weapon's computer. Now suppose that, after successfully adapting this missile to the B-52, designers decided to integrate this same missile onto the B-1B. The major issue becomes whether the software written for the B-52 can be used on the B-1, or whether the B-1 requires new software. Recall from chapter 2 that the B-52 and the B-1B use the Jovial software language and have the same type of avionics computer. This arrangement allows designers to conclude that they can use B-52 missile software in the B-1. Unfortunately, this is not true.

Little, perhaps none, of the expensive software designers write for the B-52, B-1B, and B-2 is transportable between aircraft without a significant rewrite. This limitation not only hinders the process of adapting systems already in use on one bomber but not the other; it also hinders the adaption of a new system on more than one bomber simultaneously. This limitation causes an unacceptable increase in costs.

What can designers do to promote avionics bomber software reusability? They can initiate a program to modify the software of all three bombers to some common bases. Because software reusability poses a pervasive problem, not only with bombers but across the Air Force, the Department of Defense is searching for possible solutions. Common Ada Missile Packages (CAMP), one DOD reusability project, creates a large library of reusable software and a parts engineering system to assist users in constructing application software from the components in the CAMP library.<sup>15</sup> From the CAMP project, Brian Shelburne of Wittenberg University and Marc Pitarys of Wright Laboratories drew several recommendations on software reusability. Their recommendations, summarized in table 6, offer essential lessons for any program undertaken to modify existing bomber software to increase reusability.

No simple solution for the lack of reusability in bomber software currently exists, and no agency has initiated an effort to find a solution. The reasons for this inertia are unclear, but the reasons may be that designers developed the software over an extended time period, that different contractors developed it, or that these designers compartmentalized the software in secrecy. Regardless of the reason, users are currently ignoring a potential gold mine of additional capacity. If designers can migrate bomber avionics software between aircraft, users will reap huge benefits by being able to take a big step toward instant integration of new or uncommon systems, which include weapons, sensors, communication equipment, and many other items.

The search for reusable software should begin in areas where modularity is likely. Modularity exists where the internal elements of a section of software are tightly bound or related with light interconnections.<sup>16</sup> In other words,

**Table 6**  
**Avionics Software**  
**Reusability, Observation, and Recommendations**

- **DOCUMENTATION FOR A SOFTWARE PART IS CRUCIAL**

The documentation should state explicitly the meaning of all constraints on input and output.  
 Quality documentation is a necessary precondition for any effective software reuse.

- **THE QUALITY OF SOFTWARE IS CRUCIAL**

Every effort must be made to assure the user of the quality of the software part.

- **WHEN DESIGNING A PARTS ENGINEERING SYSTEM, TWO GOALS APPLY:**

1. The selection criteria should allow the user to quickly narrow down the mass of available parts.
2. The system should display the relevant information about a candidate part quickly so the user can decide whether to use it.

**Source:** Brian J. Shelburne and Marc J. Pitarys, "Avionics Software Reusability, Observation and Recommendations," *NAECON 91 Proceedings*, May 1991, 614.

modularity means that a portion of the software has an identifiable module and that users can easily remove it to another system. One can believe quite easily that designers could find some identifiable, transportable modules among bombers with similar missions and the ability to carry the same weapons and sensors. Perhaps this end result requires a modification to the existing software architecture or a move to a different type of processing. Whatever the case, when designers enhance the reusability of bomber avionics software, they greatly increase the possibility of reducing acquisition expense while expanding the capabilities of bomber aircraft.

### **Architecture Modifications**

Designers need to modify the current program architecture to reach the fullest potential of the bomber software. More precisely stated, each bomber's software code may require a structure modification to make it easier for designers to integrate new systems and to provide greater commonality between bomber types. With the exception of the B-52, which, as discussed in chapter 2, can add weapons with minor impact to the operational program, adding a new system such as a weapon or sensor to a bomber requires a complete remake of the flight software. And, even though the three aircraft types use the Jovial language, they cannot share the same routine.

The architecture created by the B-52 Integrated Conventional Stores Management System (ICSMS) makes a big step in the right direction toward more flexible software and provides a good illustration of the possibilities such a modification possesses. Before ICSMS, the B-52's software architecture resembled the B-1B's configuration in that designers firmly embedded the code to control the weapons in the software. Because of this structure, designers must revise the software each time they add a new weapon. For

example, when the B-1 program office integrated short-range attack missiles, Boeing revised the operational software from block 1.7 to block 2.5; when the program office added air launched cruise missiles, Boeing changed the software from block 3.5 to block 4.5. The designers of the B-52 software realized that this arrangement did not provide enough memory in the computers to add the planned conventional weapons. To solve the memory problem, the designers created ICSMS software.

ICSMS software does more than simply improve available memory—it changes the philosophy of the software architecture. The new philosophy allows designers to add weapons with little effect on the existing flight software. The concept is simple: The core software is built with provisions, called hooks, for future weapons. Therefore, when designers integrate a new weapon, they write only the software required to control the unique functions of that particular weapon. If this arrangement had been the case for the B-1 when the program office added the air launched cruise missile, Boeing would have allowed the software to remain at block 3.5 to keep the software cost of integrating cruise missiles on the B-1 at a fraction of the actual price. This philosophy of providing hooks in the software for new systems extends beyond just adding weapons.

Although the ICSMS for the B-52 was designed for adding weapons without major software changes, the architecture modification required for adding these weapons could have applied to other systems also. In other words, designers could have placed hooks in the software to add, for example, additional or different sensors. Indeed, the ICSMS added a degree of modularity to the B-52 software that was missing. Designers could expand this modularity to include such other systems common in future bombers as a laser designator or a strap-on millimeter line scanner. Furthermore, because of the similarity of software and type of missions the three bombers could expect to fly, an ICSMS-type architecture modification would enhance the flexibility of the B-1B and B-2 immediately.

A general redesign of the bomber software architecture similar to, and an expansion of, B-52 ICSMS would add a much-needed capability to adapt quickly to changing circumstances, including the new requirements of conventional warfare. A new architecture is a natural extension of the concepts of code optimization and reusability. Designers would retain significant portions of the old code, but would eliminate the useless and unneeded code. At the same time, the software automatically would become much more modular, thereby improving the likelihood that designers would reuse code between bombers and also insert code from other aircraft.

Modifying the software architecture offers a major challenge. Creating the ICSMS, which again only provided hooks for weapons, required a multiyear's effort that cost millions of dollars and modified up to 30 percent of the existing code. Boeing estimates a similar effort would be required for the B-1B.<sup>17</sup> And the B-2, which contains five times more software than the B-1, would provide an even greater effort.

This revelation brings into question whether modifying the architecture is worth the expense. The first question generally asked is, "What new capability would a new software architecture provide for a multimillion dollar effort?" The answer is: "No new capability is added other than the limited capacity to add new capabilities." A software architecture modification is a capital investment in bomber futures. This investment would yield significantly decreased time and costs of integrating a future system as the needs arise. Therefore, a new architecture would make for a smart business decision if we expand the capabilities of the bomber to meet the changing requirements of an expanded conventional role.

If designers categorize a software architecture modification as a capital investment, they must consider all possible present and future requirements to ensure that the investment is well suited for a future payoff. Pairing requirements (such as those listed in chap. 1) with potential solutions suggest other modifications to the architecture to enhance the return on the investment. In other words, possible modifications range widely, from the simplest to the most complex. Choosing the right modification depends on both present and anticipated needs. However, since future needs involve guesswork, the best modification provides the greatest flexibility.

### **Object-Oriented Software for Distributed Avionics**

For bombers, the best software architecture modification capital investment may be aligned with a hardware change to the central computers. As mentioned above, new hardware almost always requires a companion software change. The hardware options discussed below require either minor or major software changes, but only one—distributed avionics—requires a new software architecture. Transforming the existing federated avionics into a distributed system aligned with a software architecture modification creates a computer complex with almost unlimited growth potential.

In simple terms, distributed avionics tie together the computers within the aircraft under a master computer which efficiently distributes the computing tasks. With such a system, operations become much like a network system in a modern office. A detailed discussion of distributed avionics appears later in this chapter in the "Distributed Processing" section of "Hardware Opportunities for Bombers," but for now, I want readers to understand the need for an associated major change to the operational software. This change, like those discussed above, affects the basic architecture.

To take full advantage of a distributed avionics complex, designers must replace the existing executive function in each of the central computers with a communication routine that attaches each computer to a master-server. If this arrangement sounds complicated, consider your home computer. A home computer works independently, and even if connected to another computer by a modem, it still does its calculation without assistance. The avionics computers work much the same way. Each has its own routine to calculate and data to process. Once loaded into the computer, the software executes a

task without assistance. However, if the operator added an efficient master-server computer, a communication node would replace the independent executive software in each computer so that the master-server computer could treat each computer as a dependent object. The master computer then would allocate various tasks to whichever computer in the distributed system that could most efficiently execute the job.

Although a distributed avionics system would create a large (and expensive) impact on the existing software, the payoff to the new software architecture would be great. Once designers replace the executive software with an object-oriented communication node, they would be able to substitute dissimilar computers and software beneath the communications node. This arrangement provides flexibility by allowing greater use of off-the-shelf software resources (i.e., enhanced reusability), retaining almost all of the existing subroutines, significantly improving operating efficiency, and providing practically unlimited software growth potential. Of these four benefits, greater efficiency and growth potential encompass the desperate needs of the three bomber types.

## **Hardware Opportunities for Bombers**

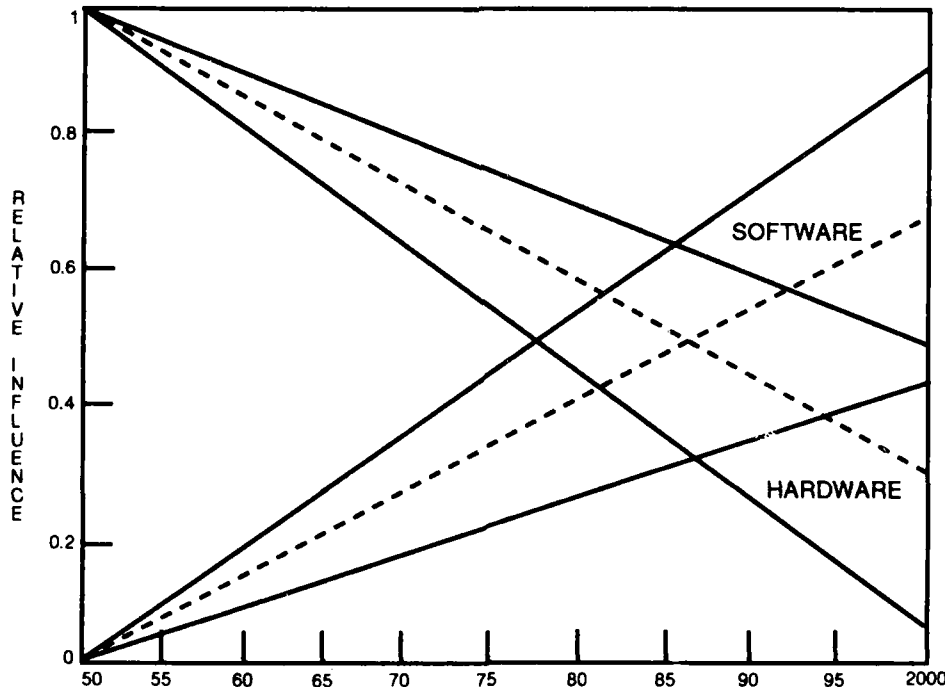
The above discussion makes it clear that software offers a variety of opportunities, even though software alone may not provide the flexibility needed to address multiple new requirements. And, as with software, hardware technology insertion concepts possess several solutions to the bomber needs. Chapter 1 identified the major categories of needs as improved target destruction; improved command, control, and communications; and improved onboard mission management. Each of these categories requires better (or larger) computer capacity. Achieving greater computation capability therefore is the primary goal of hardware technology insertion.

To repeat, options for meeting this goal range from modifying a small part of each avionics computer to replacing major portions of the avionics complex. In addition, which option, or group of options, is the best depends on current and future requirements balanced against affordability. For the sake of simplicity, let us examine four general hardware technology insertion concepts: (1) improving the computation speed of the individual computers by inserting a new processor; (2) improving the input/output (I/O) speed and openness of the avionics system by inserting a new, high bandwidth, common backplane (HB/CB); (3) improving the overall system performance by moving to a distributed architecture; and (4) improving aircraft capabilities through the use of unembedded expansions to the existing avionics complex. But, before we explore these technology insertion concepts, we must establish an understanding of where the bomber's federated computer complex falls in the evolution of avionics systems.

## Hardware Development

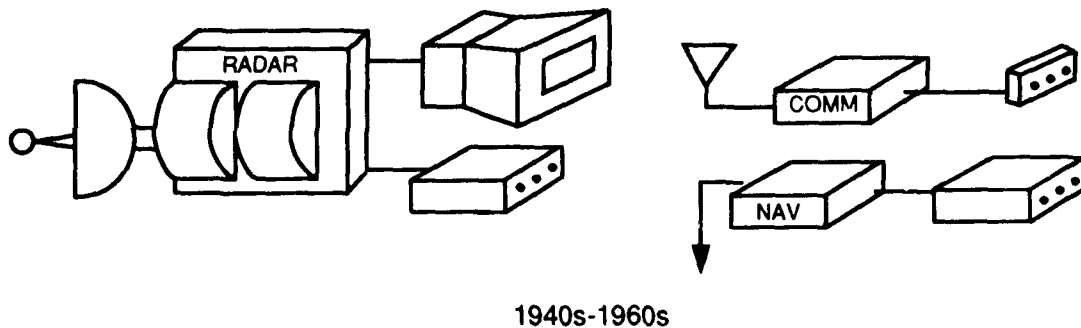
Chapter 2 already has discussed how the use of avionics has been expanding at an ever-increasing rate. Its development has progressed from a time when avionics were just a cross-check of the pilot's skill to today, a time when most modern aircraft would not complete their mission and some may not remain airborne without sophisticated computers and software. Another occurrence within this trend reveals the nature of the general evolution avionics. This second trend allows the increasing use of software to replace hardware systems or, in other words, uses software to mimic functions that hardware ordinarily performs. The Defense Systems Management College believes that "software is no longer merely a part of the system; software has become a system in its own right and has assumed the integration function for the various subsystems of a weapon."<sup>18</sup> Figure 17 illustrates this point. The increasing use of these two trends regarding avionics and software intensity has been the driving force behind the evolution of avionics complexes.

The use of computer systems in aircraft has evolved through four distinct generations, from avionics that generally operated independently to the advanced avionics envisioned for future systems. Bill Whitehouse of Boeing Defense and Space Group, Military Airplanes Division, has depicted and summarized each generation of avionics advancement.<sup>19</sup> Figure 18 shows the first generation that ran through the 1960s when avionics were independent



Source: Defense Systems Management College, briefing paper, Fort Belvoir, Va., 1991.

**Figure 17. Software Impact on System Design**

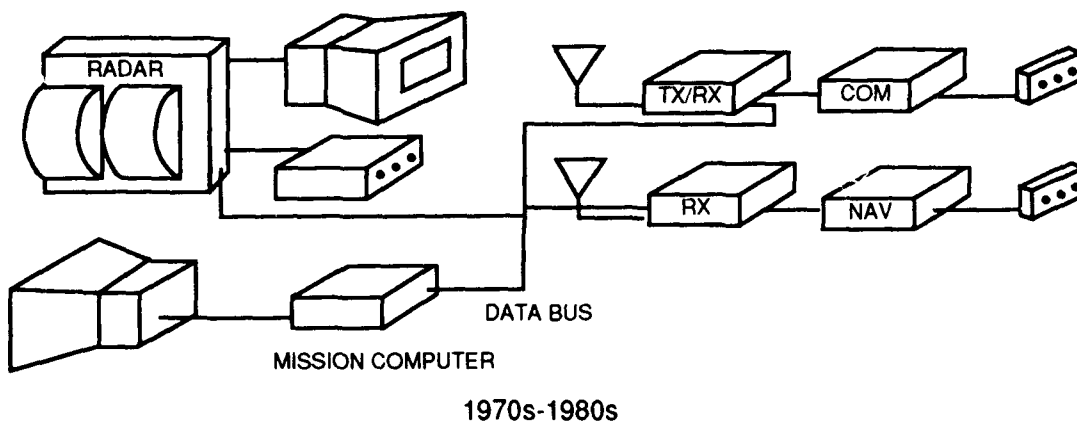


Source: William Whitehouse, Boeing Defense and Space Group, Military Airplanes Division, subject: Advanced Avionics Architecture, briefing, March 1992.

**Figure 18. Independent Avionics**

of each other. In other words, whenever designers used such avionics as the radar and the navigation systems, they began to realize that the systems did not communicate with each other and that systems integration consisted of only simple compatibility issues such as aircraft wiring, power needs, controls and displays arrangements, and space (within the cockpit) requirements.

The second avionics generation began in the 1970s and continued through the 1980s, with avionics consisting of federated subsystems. In this context, the term *federated* means that designers joined independent subsystems in federal union or under a central control. This is the configuration of most of our modern military aircraft, including all three bombers, the F-16, F-15, and even the space shuttle. Figure 19 depicts a simplified federated avionics system. The independent subsystems, with greatly increased computation capacity over the first generation, are connected to a central computer complex through the MIL-STD-1553 data bus. The integration of a federated system included the items from earlier avionics that were advanced enough to include standardized communication between the avionics computers and

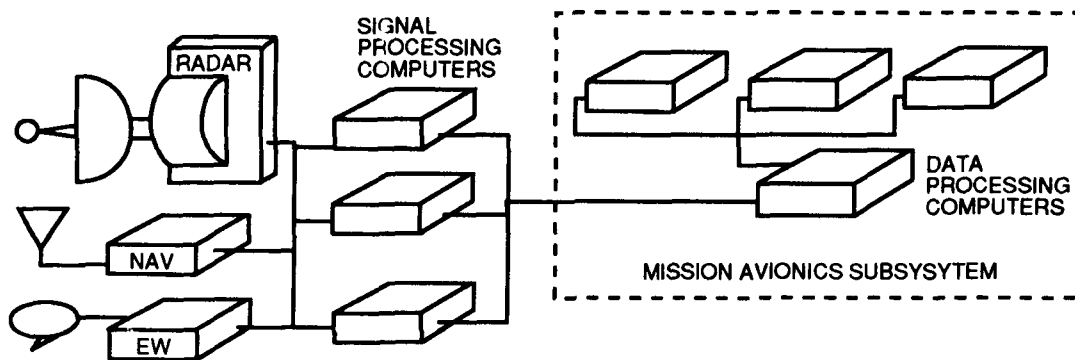


Source: William Whitehouse, Boeing Defense and Space Group, Military Airplanes Division, subject: Advanced Avionics Architecture, briefing, March 1992.

**Figure 19. Federated Avionics Subsystems**

remote terminals and integrated controls and displays. Federated avionics have served their aircraft well, but the need for improved computer performance and their lack of growth potential limit their continued use.

To solve the computer performance problems for 1990 aircraft development, the Air Force instituted the Pave Pillar program. This program produced a third avionics generation to achieve a truly integrated avionics system. Figure 20 shows a simple integrated avionics system, and figure 21 depicts the actual complex Northrop envisions flying on the advanced technology fighter. Within an integrated avionics system, a cluster of high-powered, data-processing computers can be expanded as growth is needed to control computations. However, a Pave Pillar system still does not take advantage of the tremendous computer capabilities currently unfolding.



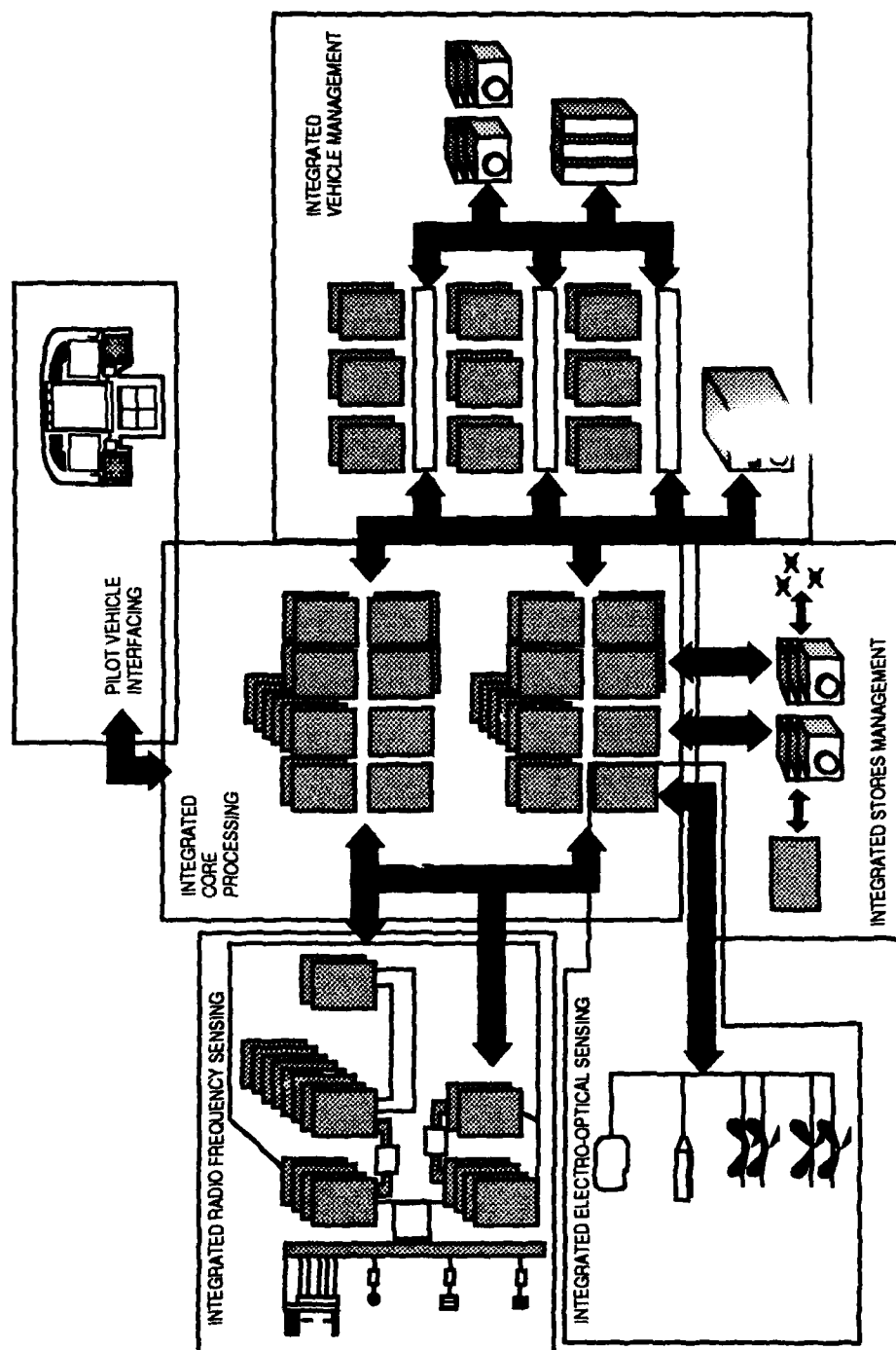
Pave Pillar 1990s

Source: William Whitehouse, Boeing Defense and Space Group, Military Airplanes Division, subject: Advanced Avionics Architecture, briefing, March 1992.

Figure 20. Integrated Avionics System

Realizing that available computer performance is rapidly advancing and that software is replacing many hardware functions, the Air Force began the Pave Pace program to design advanced integrated avionics (forth generation). An advanced integrated system decreases the number of avionics data processors to perhaps only one super master-server computer. Also, a significant portion of the hardware needed today is embedded into the software, and the number of common modules will increase. A Pave Pace-type avionics system such as that shown in figure 21 falls well within the capabilities of today's microcomputers.

Armed with this knowledge of the evolution of avionics, designers have found that the task of improving the performance of bomber-federated avionics systems has become clearer. In general terms, the second generation systems installed in the B-52, B-1, and B-2 perform adequately for the missions these aircraft were originally assigned, but these systems lack the needed performance and growth potential to accomplish the expanded roles required by a changing world order. To meet the requirements outlined in



Source: Air Force Avionics Laboratory, briefing paper, 1992.

**Figure 21. Avionics Architecture**

chapter 1, the avionics must process much more data faster and still have enough growth potential to absorb added systems. In short, designers must find a method to insert fourth generation avionics into the second generation systems the bombers currently use.

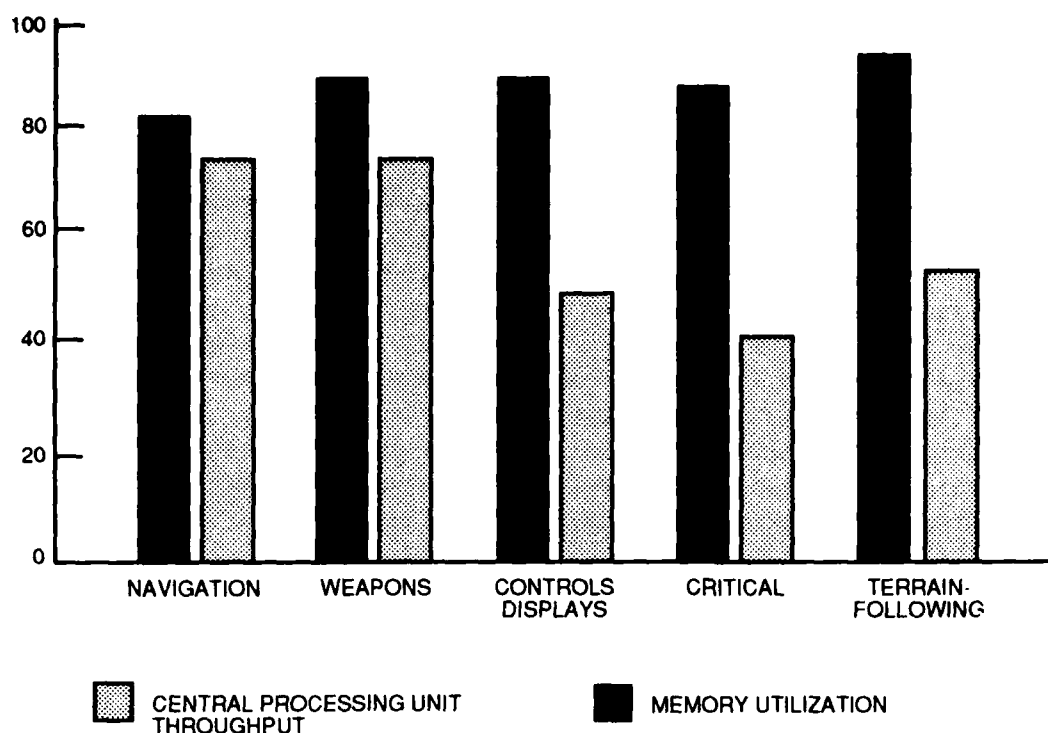
The best approach to achieve quasi-fourth generation avionics in our bomber force examines the basic building block of the existing system and inserts new technology, perhaps piece by piece, working toward an advanced integrated avionics suite. To this end, the examination appropriately begins with the processor in the central computers. After designers achieve performance improvements in the central computers, they should then try to improve input/output time. From this point, moving to an open avionics architecture brings the complex within reach of our desired outcome—an advanced integrated avionics suite—a system with almost unlimited growth potential and much-improved flexibility.

### **Inserting a New Processor**

As repeatedly stated, the central computers in the B-52, B-1, and B-2 have nearly reached the end of their growth potential. By today's standards, these computers have a small memory capacity (generally either 128K or 256K RAM) and operate at a slow speed (approximately 1 MIPS). The B-1B central computers illustrate why this is a problem. In the estimation of Rockwell International, the prime contractor for the B-1, providing the aircraft with a proper conventional capability exceeds the performance capacity of most of the existing central computers.<sup>20</sup> Figure 22 shows current throughput and memory utilization, while figure 23 shows what happens to throughput and memory after the integration of a conventional capability. Notice that three out of five computers exceed their memory capacity and that at least two of the five did not have enough throughput to handle the work load. If Rockwell's estimations hold true, then we must realize that integration of new tasks on the B-1B will either be somewhere between difficult to impossible or will not be achievable at all.

What then can be done to improve the capacity of central computers such as those on the B-1B? The most likely solution demands that we replace the processor (the equivalent of the mother board on a personal computer). To understand how to implement such a solution, let us briefly examine the inside of the computer. Figure 24 shows the features of a typical, general purpose avionics computer. The individual cards, called shop replaceable units (SRU), resemble the circuit cards in a home computer. Several of the SRUs handle memory storage or carry communication outside of the computer, and several of the other processors perform the required calculations. Because the processor's SRUs are the workhorses, replacing them with new horses improves the throughput and provides the opportunity to replace the old-style memory SRUs with modern, larger capacity, memory cards.

The processors in the central computers of all three bombers are early 1980s technology. Computer technology has advanced significantly since then.



Source: Rockwell International Corporation, briefing paper, 1992.

**Figure 22. Block 4.5 Resources**

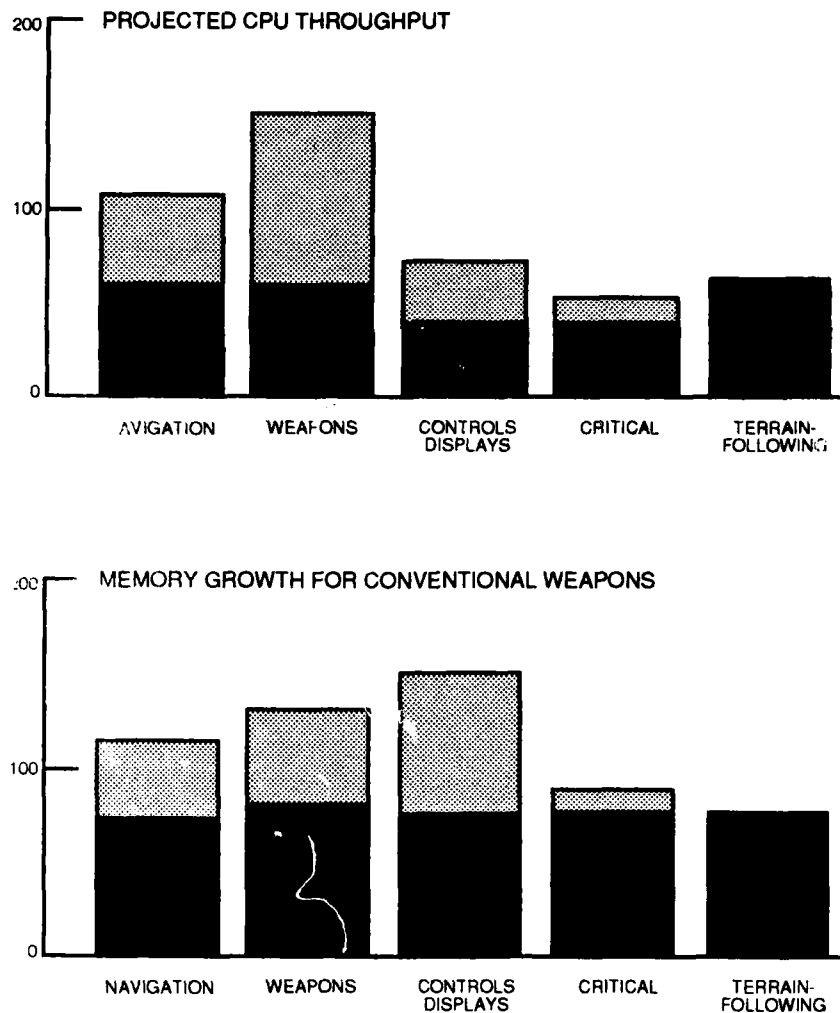
Using very high-speed integrated circuit (VHSIC) chip technology yields one of the best performance improvements. To achieve the desired throughput performance, designers could implement the processor's SRUs of a central computer on a single SRU by using VHSIC technology. IBM Corporation is now demonstrating the feasibility of this concept on the F-15E. The F-15's computer resembles those used on the B-52 and the B-1. IBM intends to replace the existing central computer with a form-fit function exactly like the function in the VHSIC version. Company officials predict the new computer, with a VHSIC processor, will operate nine times faster and contain six times the memory capacity.<sup>21</sup> Designers can do the same to any one or any combination of computers in the bombers.

The insertion of a VHSIC into the central computers has both negative and positive consequences. On the negative side, designers will find it impossible to insert a VHSIC without its having an impact on the operation of the software. The degree of impact depends on the design. A simple relationship determines the impact: The closer the VHSIC processor design comes to the architecture of the existing processor, the smaller the impact on the software. However, the more the VHSIC processor emulates the old processor, the less it can take advantage of the capabilities of an improved VHSIC. In other words, if designers build a VHSIC processor on an architecture that resembles

the existing one, the software will need little change, and the new processor will show less performance improvement.

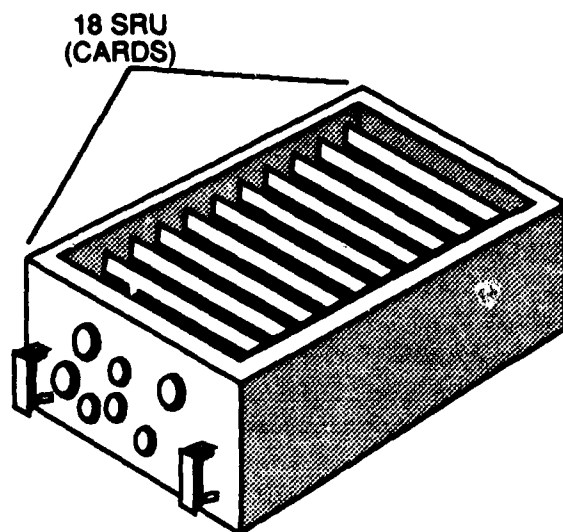
On the positive side, designers will derive many benefits from inserting the VHSIC electronics. Because the VHSIC has a smaller circuitry, designers can fit more items on the SRU. For example, designers cannot include on the processor card much of the memory that currently resides on other SRUs. Other benefits of the VHSIC include improved reliability, supportability, and, of course, speed, as mentioned above. One of the most important benefits of the VHSIC is that it has a technologically proven and DOD-sanctioned concept for enhancing computer performance.

Despite the above-mentioned advantages, designers must consider several variables before jumping on a VHSIC processor bandwagon. The software,



Source: Rockwell International Corporation, briefing paper, 1992.

**Figure 23. B-1B Projected Computer Performance Required**



- 18 SRUs
- 1 MIP/256K WORD
- PROVEN SOFTWARE
- NEAR LIMIT ON THROUGHPUT MEMORY
- CLOSED ARCHITECTURE

Source: Boeing Corporation, briefing paper, 1992.

**Figure 24. Typical Central Computer**

already discussed, is one. Computer configuration is another, and a third is external communications. Computer configuration applies to the arrangement of the SRUs inside the computer box. Inserting a VHSIC processor decreases the number of SRUs needed to perform the same functions, thereby freeing a large number of currently used slots. The requirements planner should consider whether these slots should remain empty (for future growth) or, if possible, whether to use these slots to combine two or more central computers in one box.

The external communication may prove the most pivotal for future growth. Currently, the computer communicates with other systems through the 1553 data bus SRU. It is possible that, after the computer begins to work much faster (by inserting a VHSIC processor), the next bottleneck centers around the I/O rate. This rate may then become the limiting factor in adding new weapons and sensors. The requirements planners must decide if the 1553 data bus I/O rate suffices. If it does not, designers should configure the new VHSIC processor to handle faster I/O, or *even* better, they should design it to handle both the current rate and open the architecture for whatever the rate may be when they devise a new standard.

### **Designing Open Architecture**

Moving our bombers to an open architecture in their avionics computers may be the most essential way to remain flexible enough to adapt to changing requirements. In an article in *Defense Computing*, Dick Naedel, president of Intellimac Inc., remarked, "Open architectures offer an inexpensive alternative to costly special purpose hardware and software." He continues:

In order for embedded military computing systems to maintain technological superiority after deployment, their design must be founded in open architecture. By carefully engineering this open architecture approach at both the hardware and systems software levels, maximum technology insertion capability can be achieved with minimal impact on logistics support.<sup>22</sup>

The data bus over which the central computers receive information and distribute commands holds the key to providing an open architecture.

As explained in chapter 2, the capable and common data bus of the bomber is the MIL-STD-1553. Used by operators since 1973, the 1553 bus now appears on ships, submarines, missiles, satellites, launch vehicles, and the M1-2A tank. The US also plans to use the 1553 in space station *Freedom*. The bus controls data at a speed of 1 MHz and is limited by message overhead to a maximum average data rate of approximately 730,000 bytes per second (KBPS).<sup>23</sup> Because of its many applications, the 1553 will likely prevail for some time, but this does not negate the possibility of the need for higher speed data communications between computers.

To enhance the computing capacity and throughput of the overall system, the individual central computers must communicate with each other without interfering with communications outside the computer cluster. The best method to achieve this type of communication is to move to an HB/CB tie between the clusters. An HB/CB could offer a natural way to rebuild the processors with VHSIC technology. As designers reconfigure the processors to operate at the higher speeds and make room for additional SRUs within each computer, they could add a new I/O card—one compatible with the new VHSIC processor—to link the computer clusters and also to interface them with the existing 1553 data bus. Figure 25 shows what an open architecture system would look like. This structure allows the subsystems in the central computer to work together as an entity rather than as individuals to produce a synergistic effect and to enhance the computer complex's performance capacity and future growth potential.

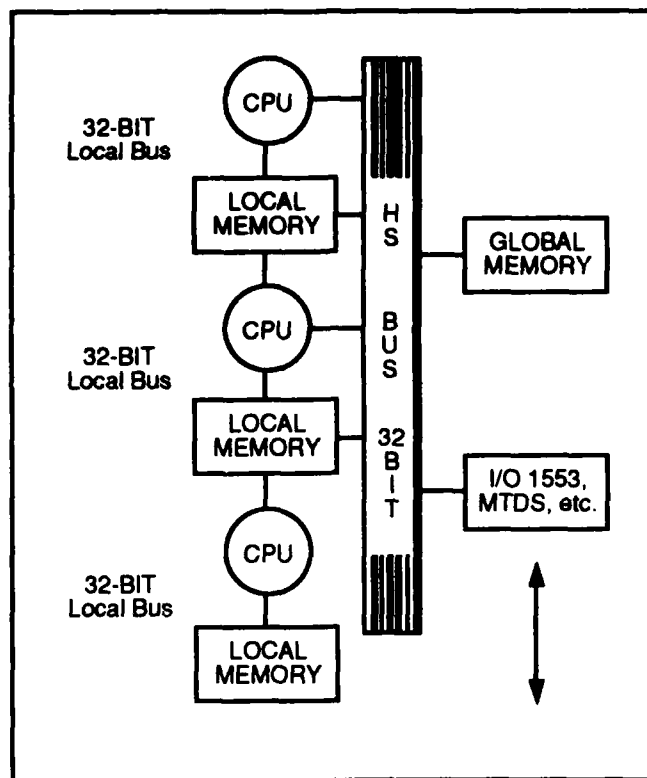
Opening the architecture by inserting a VHSIC processor and tying the central computers together with a high bandwidth data bus can provide several benefits. In the words of Dick Naedel:

The implementation of open architectural design standards in embedded military computer systems provides the end-user with the following benefits: continued technical superiority via rapid technology insertion capability; competitive sourcing for hardware and software components, hence a lower life cycle cost; lower costs through common reusable software; and simplification of logistics support.<sup>24</sup>

Beyond the above benefits, installing a system such as this one in our bombers provides a practical first step toward a distributed architecture.

### **Distributed Processing**

The previous Software Opportunities for Bombers subsection above alluded to the possibility of transforming the existing federated avionics complexes into a distributed system. This concept seeks to move bombers from second to fourth generation avionics. Remember from the previous discussion that



Source: Dick Naedel, "Open Architecture in Military Computers," *Defense Computing*, March-April 1988, 52.

**Figure 25. Open Bus Architecture**

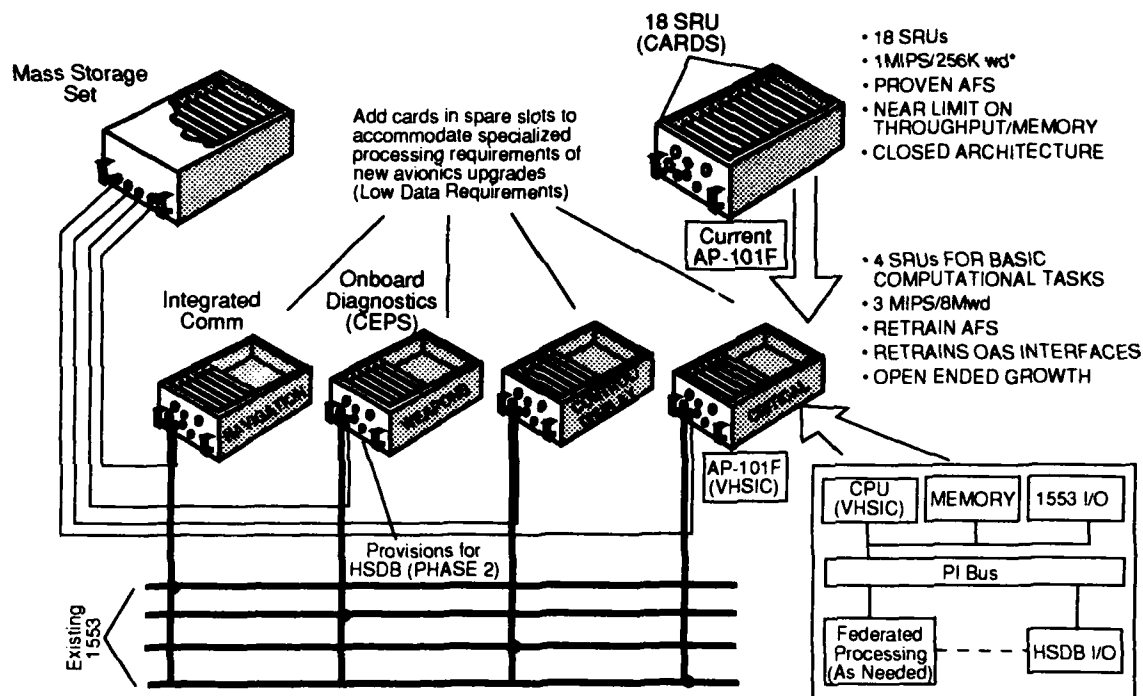
distributed avionics resembles an office network; that is, instead of allowing the computers to function independently, they are arranged to work together under the supervision of a master-server computer. The distributed processing concept applies to such large computer complexes as those found on aircraft and ships. Boeing, IBM, Honeywell, and other avionics contractors are actively researching distributed system prototypes. For example, IBM outlined their new design for a submarine computer system in "Dazzling Technology," an article that appeared in their company's monthly newspaper. It stated that the computer system

provides newly designed mine detection and avoidance, under ice navigation capability, expanded active sonar capability and a fully integrated system to accommodate an enhanced range of weapons. The system employs distributed processing architecture, thereby eliminating potential single points of failure found with centralized processing.<sup>25</sup>

Even though, in this case, the computer complex is about half the weight of a B-1 (32 tons), the concept is the same. Creating a distributed architecture reduces the limitation of the existing federated systems. To understand the implementation of a distributed system in bombers, we need to take a closer look at the difference between federated and distributed avionics.

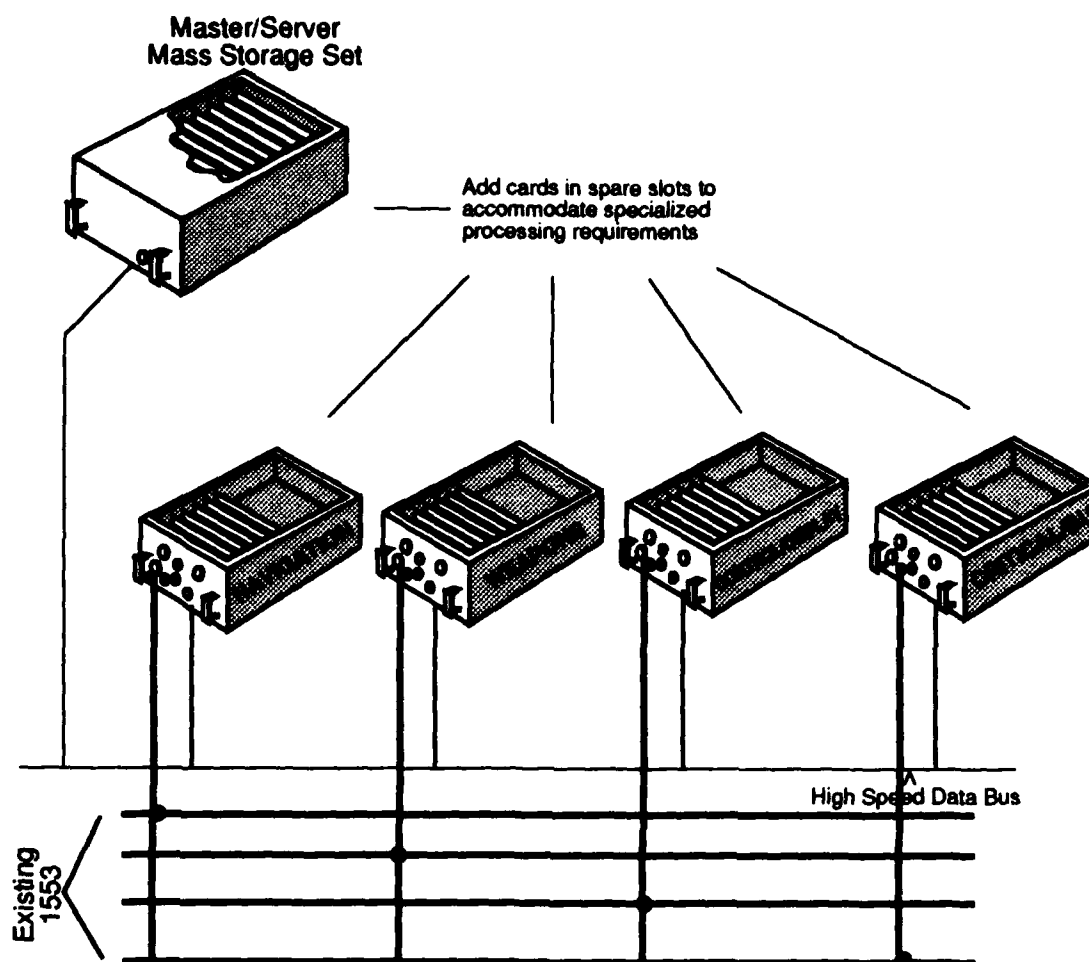
Recall from the previous discussion of second generation avionics that a federated system consists of independent avionics joined by a central complex. Figure 26 shows an avionics complex much like the one used in the B-1B; however, the central computers illustrated already have received the VHSIC processor and the virtual memory extension data bus interface upgrades discussed above. Notice that the system retains its federation. In other words, each computer communicates only through the 1553 data bus to execute its tasks (which are assigned during the preflight mission software loading) independently. Since no direct communication exists, individual computers have no knowledge of what the other computers are doing (or perhaps, more importantly, not doing). The central computers communicate with a storage computer which passes data for processing when required. This system has no entity to monitor the computation status of the complex; no computer is in charge.

Contrast this scenario to the distributed avionics system depicted in figure 27. The computers still communicate to the rest of the aircraft through the 1553 bus; however, a high-speed data bus (HSDB) now ties the central complex together, and a master-server has now replaced the storage computer. The master-server



Source: Boeing Corporation, briefing paper, 1992.

Figure 26. Enhanced Federated Avionics



Source: Boeing Corporation, briefing paper, 1992.

**Figure 27. Advanced Distributed Bomber Avionics**

is also tied to the HSDB. We can now take maximum advantage of the computation power of each computer and of the computer complex as a whole. Designers can distribute new tasks into the individual computers, because the computers can communicate with each other directly and because there is new room in each computer due to the insertion of VHSIC technology. The most important aspect of this design is the function of the master-server. This computer has two primary tasks: (1) to act as the master by distributing various tasks and monitoring their execution and (2) to serve as an additional (and potentially powerful) computer within the network. Because the design of the master-server plays a pivotal role in the layout of a distributed avionics system, the design requires a careful examination.

What should be the makeup of a master computer for the entire avionics complex? First, it should encompass the best technology available. The best candidate most likely will be a high-speed, 32-bit architecture. The master-server

must have both internal and external expansion capabilities. Inside, the box should have enough room to insert additional processors for parallel processing when the need arises and to add more storage cards for future needs. The box must have true mass storage. Outside, the computer must allow users to add other computers, including computers of dissimilar architecture and software, on the high-speed bus. Since the master-server would play a critical role in the smooth execution of the mission, it must be fault-tolerant (i.e., it must not be prone to catastrophic failure). Being fault-tolerant also means that when minor failures occur, they should have minimal impact on aircraft operations. Recognizing that even fault-tolerant systems can fail, designers must not make the master-server indispensable. If it does fail totally, it should allow the avionics system to degrade gracefully to provide a system that is at least as good as the one that currently exists. The master-server should have an extensive list of requirements that all fall well within the ability of present technology.

### **Unembedded Expansions**

The final hardware technology insertion area focuses on the concept of expanding the aircraft's capabilities by inserting, or perhaps attaching, complete systems which are not embedded into the avionics, but ones that designers can move easily from one aircraft to another. One can easily envision several reasons to construct an unembedded system. For example, designers may find the add-on system to be either too expensive or too specialized for mass construction. Or, they may find that users have a need to share a system that was originally built for a different type of aircraft. Whatever the reason, designers must consider provisions for the integration of unembedded avionic systems.

An example may help to explain unembedded expansions. Suppose a bomber requirements planner is looking for a method to gain more computation power for a specialized bombing mission. A clever method of obtaining additional computer capacity would be to devise a method that would allow the master-server computer to assign tasks to the bombs. Many of today's modern weapons have computer systems with warheads. Experts in the field refer to one such weapon, a 500-pound guided bomb, as an inertially aided munition (IAM). The IAM has in its tail a reasonably advanced specialized computer, which is much faster and has much more memory than any one of the central computers in the B-1B (about 8 MIPS throughput and 1M of RAM). A bomber can carry up to 84 of these weapons within its bomb bay. These 84 computers have nothing to do except to wait to be dropped. Operators could use the bombs to form a type of neural network of artificial intelligence that could be tapped inbound to the target area. Some observers may argue that designing such a system and then dropping the bombs would rob the aircraft of needed computer capability. But usually, as designers release the weapons, they find less and less need for sophisticated calculations. This example seems a little impractical, but it is possible if designers plan for an inserted distributed avionics system during the design phase.

Another more practical and more likely example includes the possibility of "strapping-on" such scarce weapon systems as sensor or electronic warfare pods that the designer must move from one aircraft to another. These pods most likely would contain a variety of computers which have specialized tasks and generally sit idle throughout most of the mission. Once again, if designers configure the avionics system with sufficient flexibility, they could use the master-server computer to assign tasks to the pod when the pod's computers are not being used for their primary mission.

With a well-engineered avionics complex, designers have unlimited possibilities to expand the system. The existing bomber avionics have almost no capacity to add any system, whether it is embedded or not. When modifying the hardware to add the needed capacity, designers must consider two concerns: (1) keep the primary objective in mind and (2) maximize the computer system's flexibility.

## **Concepts for, and Impacts on, Preflight**

To this point, we have discussed only technology insertion concepts that improve the in-flight capability and flexibility of the onboard avionics. This concept leaves open two important questions: (1) Is there a concept that improves aircraft maintenance (or availability), preflight mission planning, aircraft simulator, or daily training? and equally important (2) What is the impact of implementing the above concepts? Here again, inserting new technology cannot solve every problem of the bomber fleet, but it can address ways to make some of these problems manageable.

### **The Maintenance Connection**

The best way to destroy targets from the air is to prepare the aircraft for flight and to maintain it airborne without any major disabling malfunctions. As our bombers have employed increasing amounts of electronics, preparing them to fly and keeping them healthy in flight have become increasingly complex. Theoretically, filling aircraft with more "black boxes" and software to replace bulky mechanical devices should have improved the maintainability, but this has not happened. The black boxes failed at discouragingly high rates. For example, the B-1B's radar signal processor (radar computer) had a 525-hour mean-time-between-failure (MTBF) rate.<sup>26</sup> This showing was poor when compared to the Air Force goals of reliability and maintainability (R&M) 2000. Technology insertion programs must address reliability and maintainability issues and keep the basic goals of R&M 2000 as a primary design issue.<sup>27</sup> The bottom line calls for an inserted system that must be more reliable, supportable, and maintainable than the components they replace.

**Reliability.** The Air Force generally uses MTBF to measure system reliability. Difficulties sometimes occur when the Air Force uses this measurement because the fickle nature of computers often causes them to fail

temporarily and without warning. Militarized computers are not fragile; they endure severe heat and stress, which cause intermittent or difficult-to-duplicate malfunctions. Furthermore, the software must operate under circumstances that are equally difficult to duplicate, even in the lab, and software failure may appear to be a computer failure. Therefore, the MTBF rate on the computers yields a low number, which means that designers spend long (and costly) hours on maintenance.

Technology insertion improves avionics reliability in several ways. First, and perhaps foremost, the insertion can replace worn or poor-quality parts (including software parts). Secondly, the new technology is almost always a downsized version from the older technology circuitry. This means the individual computers need not be filled with circuit cards to perform the same function. Having fewer cards reduces the power consumption and internal heat, which are a primary cause of computer failures.

Probably the best way to improve reliability is to insert quality and thoroughly test the software. My experience during flight testing of the B-1B leads me to believe that many of the computer failures were eventually tracked to a software error. However, extensive flight testing of the software is expensive. This means that efficiently implementing the software modification concepts outlined above depends on offering better methods for developing and testing the new software. And, software must become increasingly fault-tolerant as it expands to fill additional computer capacity.

The final area where technology insertion can improve mission reliability is in the design of the new avionics complex itself. As mentioned above, a distributed avionics system depends on a master-server computer that must be fault-tolerant. Designers can achieve the required reliability by using redundancy within the master-server and with a well-engineered distributed system.

**Maintainability.** In the September 1991 issue of *Avionics Magazine*, Tim McDonough summed up the maintainability of modern aircraft well when he stated:

In the days when electronics and airplanes were not exactly a match made in heaven, malfunctioning avionics were quickly repaired with tubes, wire, and solder. Aircraft availability was not affected because most avionics were not flight critical. With the transistor and miniaturization, however, came more complex and essential, airborne electronic systems. In the military, the increased complexity had terrible effects on reliability and maintainability.<sup>28</sup>

A paradox of avionics holds that, even though the maintainability of the system becomes increasingly complicated as the individual systems become more sophisticated, the move to sophisticated systems simplifies the maintenance process. You may wonder how could this be? The answer lies with the rapidly improving diagnostic capabilities of computers in general and with the avionics complex itself if it's properly designed. More and more, the maintenance technician is turning to the computer to assist in maintaining the aircraft; and the aircraft themselves, even with existing equipment, oftentimes accurately report system failures.

Technology insertion concepts that improve maintainability fall into two broad categories: (1) better onboard data collection and diagnosis, and (2) better ground support equipment. In both categories, advances in computers and microelectronics form the bases for progress. In addition, advances in software, particularly knowledge-based software, have allowed the machine to replace (theoretically) much of the crew chief's expert knowledge that is needed on the flight line. Meeting the maintainability requirements for future wars depends on the implementation of these technology insertion concepts.

For the first category, great strides in maintainability rates are available through better in-flight (on-aircraft) malfunction recording and diagnostic equipment. Because of the advances in miniaturization, a new SRU inserted into an avionics computer can record the computer's entire moment-by-moment history. These recordings provide the maintenance technician with such priceless data as heat stress or card component failures to help decipher the malfunction.

On a larger scale, beginning with the B-1B, the bombers have a computer which periodically records the health of the avionics throughout the aircraft. Again, the data collected is priceless for malfunction analysis. However, this data is so voluminous that it can take hours to sort through, detracting from the time spent fixing the problem. To help circumvent this dilemma about the B-1B, engineers designed a limited, ground-based, expert-parameter computer analysis system. The term *expert-parameter* (sometimes called knowledge-based) means the computer uses the same parameters (expert knowledge) that a senior crew chief would use to analyze the malfunctions. The computer shifts through the raw data recorded during the flight to determine the validity of each malfunction, just as the crew chief would read through a computer printout of the same recorded data. The *expert-parameter* computer is little more than a standard, powerful desktop system and could easily be militarized and embedded in the avionics complex, particularly in a distributed avionics system.

A variety of benefits to having an expert-parameter diagnostic computer system on board exist. First, the system provides an immediate information source for postflight maintenance. The flight-line crew chief can begin to repair the aircraft as quickly as he or she can download the computer's analysis of the mission. Second, the flight crew would have a valuable tool to assist in in-flight maintenance. In theory, the scenario resembles having a maintenance technician flying with the crew on every mission and advising them on the best course of action to remedy equipment problems. And finally, if operators tied the expert-parameter computer to an onboard mission management computer, they could feed the malfunction analysis directly, to help adjust the mission execution based on current and predicted system health. Thus, the technology insertion concept not only improves maintenance efficiency but also enables the flight crew the added flexibility to make rapid, accurate in-flight adjustments.

There are also abundant computer resources to make improvements in the second general maintainability category—ground support equipment. Here

again, miniaturization and inserting expert systems into the maintenance process improve efficiency. One of the best examples of this potential focuses on the use of hand-held (even smaller than lap-top) personal computers (PC) as part of the maintenance technician's tool kit. Due to their availability and capability, operators use PCs to replace dedicated avionics test equipment. PC-based test equipment can be created either by inserting specialized cards into a standard PC, or sometimes simply by using tailored software. For example, Sigmatek's reduced-complexity automated test uses a standard PC with no added plug-in boards (cards). The system needs only an interconnect cable to construct a test set that is affordable, transportable, and easy to set up.<sup>29</sup>

There are many benefits to testing with off-the-shelf computer hardware to replace specialized avionics test equipment. The most important benefits include greater availability and improved capability of the standard PCs. Availability means that when one computer does not work (or has been overworked), the maintenance technician can move on to another one. Improved capability means that these PCs execute the same test better and that they perform additional tests functions also. For example, storing the maintenance manuals and repair checklist cross-reference hard drive is well within the capability of laptop PCs. Another example is creating a hand-held PC with a model-based diagnosis capability that "plugs in" to the aircraft's avionics bus.

Inserting up-to-date recording and diagnosis computer systems into both onboard systems and the maintenance process itself holds the promise of improving maintainability. Robert McAfoos of Honeywell Systems and Research Center correctly summarizes the process:

The maturation of expert systems for maintenance and diagnostics is providing the potential for a revolution in the maintenance process. Significant maintenance aids will be available to the technician that will improve his diagnostic accuracy and efficiency. These systems also provide the potential to reduce the life cycle costs of the maintenance infrastructure within the US Air Force.<sup>30</sup>

Improving the maintainability of existing systems encourages the concept of expanding the use of additional systems and, in total, contributes to the overall flexibility of the aircraft.

**Other Impacts.** The technology insertion concepts impact nonflight operations in many areas. For example, designers should not modify the aircraft, particularly with new capabilities, without first modifying the aircraft simulator. However, as with the aircraft, the simulators have expended most of their growth potential. Fortunately, technology insertion can provide the same benefits to the simulators, but not without careful planning. Any program, whether software or hardware, must include the simulator concept. Similar to simulator, inserting new technology on the flight crews must be considered before modifications begin. The relationship of the concepts to daily training and (off-board) mission planning may hold the vital link to the effectiveness of the technology insertion. To ignore these factor's risks would make these systems unusable.

## What It All Means

At this point one may assume that the technology insertion concepts advocated in this section are vague or ill defined or perhaps not executable from an engineering perspective. Worse, the concepts may leave many observers wondering, "Where is the war-fighting improvement?" One may find it difficult to understand how the practice of inserting changed software or how new computers translate into more enemy tanks destroyed. The defense of these concepts boils down to one simple phrase: improved flexibility. The added flexibility of better software, advanced hardware, and better R&M forms the bases upon which war-fighting improvements are built. But even more basic, attempting to add war-fighting improvements without first addressing these concepts may be a recipe for disaster.

In a similar way, the air campaign commander may conclude that loading more bombs on each aircraft may increase the likelihood of destroying the target. But, if loading more weight overloads the wings, it also destroys an aircraft instead of a target. We must view computing systems as a fundamental element in our ability to wage war, and just as adequate wings are needed to deliver the bombs, adequate computational resources are mandatory to conduct missions effectively and reliably and with a high degree of flexibility to support mission evolution. Furthermore, if you notice that the wings cannot support the desired bomb load, fix the wings first, then load the bombs. You don't work the structure problem while you load the weapons. Likewise, we must concentrate on improving the computer capability of our bombers first. For unlike the human, who can be pushed to the limit and a little beyond, the computer pushed beyond the limit will collapse and bring down the avionics house with it.

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## **Chapter 4**

### **Strategy for Flexibility Applying the Concepts**

Chapter 1 examined the new bomber force requirements that were brought on by the need to expand the capability of these aircraft for conventional warfare. Chapter 2 highlighted the current capability of each type of bomber and reviewed the strengths and weaknesses of their avionics complexes. Chapter 3 concentrated on exploring technology insertion concepts to improve the avionics performance characteristics. Armed with this information, the reader now can investigate how best to apply the concepts of chapter 3.

Hopefully, by this point the reader realizes that, even though a degree of commonality exists between the types of bombers, no single solution avails itself to satisfy their needs. Nevertheless, the concepts outlined in chapter 3, though different in specific details, can each apply to the different bomber types. To avoid redundancy, this chapter concentrates on just one bomber type—the B-1B—and allows the reader to determine how a particular concept can be applied to such other aircraft as the B-52 or the B-2. Similar to chapter 3, chapter 4 offers general ideas that skirt engineering detail. This document does not intend to provide a how-to guide for creating a specific system, but it does provide a synopsis of modifications that are within the realm of the possible, including the ultimate goal: greater flexibility to our bomber fleet.

### **Why Flexibility Is the Key**

Paradoxically, some concepts within the realm of possibilities may provide added capacity to an aircraft, but at the same time they also may limit flexibility. Although attractive, these approaches miss the mark. Phasing technology insertion is the right approach and can be demonstrated by using the B-1B avionics complex as an example for itself and the other bombers. To help ensure that all technology advocated has war-fighting improvements associated with it, the final section of this chapter relates the concepts in the example to the needs outlined in chapter 1. Readers should keep in mind that the bottom line for the war-fighting improvement offered here enhances the flexibility to conduct diverse missions. Technology insertion programs that do not achieve flexibility will have negligible future value.

## **The Wrong Approaches**

Over the history of the Air Force, bombers have gone through many modifications, some better than others. Often, airframes outlive their electronics or outlive their missions. Certainly, time will overcome the original design attributes, and if that aircraft does not adapt, it will be parked in storage. On the other hand, designers upgraded the electronics of adaptable aircraft like the B-52 and F-111 and used them to fill many military roles. The question for these airplanes was not whether to modify them, but "when" and "what" to modify. For bombers, when was generally answered by the political winds of nuclear deterrence, and what was generally the minimum amount of new equipment required to establish a new nuclear capability.

Recent modifications to aircraft have centered around adding a specific capability that is currently lacking. In almost every case, the requirements planners exercised little forethought to provide preplanned product improvement—growth potential. For example, integrating air launched cruise missiles on the B-52 required adding what was at that time advanced digital avionics. The computer capacity of this new avionics suite covered only the existing weapons, plus the allocated space for the addition of cruise missiles. As pointed out in chapter 2, the B-52 acquired little additional capacity beyond what was required.

The changed world environment presents a new set of when and what questions for the bombers, but this time the questions go beyond simply addressing the issue of adding a new nuclear capability. The new world order, combined with the results of Operation Desert Storm, may answer these questions, and the response can easily range from one end of the spectrum, where we make no changes, to the other end, where we overreact. But one end ignores an opportunity, while the other end may produce equipment that may prove useless.

**Make No Changes.** Desert Storm indicated that our conventional air power handled a wide variety of difficult tasks. The only bomber that participated was the B-52, which delivered mostly 500- and 750-pound general purpose bombs. With the exception of the B-52's conventional cruise missiles, other aircraft completed most of the precision target attacks. The question then becomes, If we were to replay Desert Storm, would we need additional bomber capabilities? Answering "no" implies that we should leave well enough alone and not modify our bombers.

From history we learn that no war is like the last one. If we leave our bomber fleet unmodified, they will likely be inadequate to fill a meaningful role in the next conflict. But this then leaves the question of what modifications to make. Without thinking carefully, one may conclude that, since a particular weapon on a particular aircraft works well in Iraq, designers should integrate that same weapon on all bombers soon.

**Overreact or Patch.** At the other end of the response spectrum, selecting a quick solution based purely on one historical example may provide little future usefulness. It is true that designers can mate just about any modern

smart weapon with any bomber. If we perceive an immediate need to integrate a new weapon, then a significant chance exists that we will take acquisition shortcuts to mate it quickly (or while the funding opportunity avails itself). In the past, these quick additions have indeed completed the required integration with the ultimate result that, when the next war erupted, especially a different war from the one expected, the new weapon (or sometimes a new capability such as a sensor) was ineffective. Simply put, overreacting to a historical event or trying to patch an existing weapon system to achieve a quick capability may leave the aircraft impotent in a future conflict.

### **Resourceful Technology Insertion**

Sound requirements planning provides the only answer to meeting such future needs as those outlined in chapter 1. As an important aspect of sound planning, preplanned product improvements (P<sup>3</sup>I) allows the system to grow with changing requirements. Unfortunately, the bombers have been built with little P<sup>3</sup>I. In the planners' defense, however, we add that they would have found it difficult to predict the dramatic changes that led to the needs of the expanded bomber. And, although lacking P<sup>3</sup>I, the reasonably standardized design of the various avionics complexes leaves open the possibility of improvements through technology insertion.

The concepts advocated in chapter 3 potentially could resolve current system shortfalls while simultaneously providing significant P<sup>3</sup>I. The result would be aircraft with maximized flexibility. With this enhancement, the B-52, B-1B, and B-2 would not need to rely on just one new class of weapon or type of sensor; instead, they would be able to quickly integrate whatever system circumstances warrant.

**Avoiding Technology Traps.** Note that a technology insertion program also could cause an overreaction or could cause one system to become patched into another. In this regard, it would not differ from using the wrong approach as discussed above. For example, bombers suffer from the absence of a central computer performance capacity. In fact, most of the B-1's computers only have 128K of RAM—an insufficient capacity to integrate a complex new weapon successfully. A typical overreaction solution would insert unique SRUs with only enough RAM to allow integration of the new weapon. While this approach satisfies the current need, it fails to consider the overall impact on the avionics complex. The extra RAM most likely will worsen the already poor throughput performance and provide little or no additional growth capacity. Here, designers miss an excellent opportunity to improve the computer's flexibility.

Again, sound acquisition planning enables planners to avoid this type of technology trap, but do they know the meaning of sufficient P<sup>3</sup>I? Or, perhaps a better question is, Is it possible for planners to execute improvement programs that account for all contingencies bombers could encounter? Probably not, but planners should make provisions for nearly all contingencies by setting such a long-range P<sup>3</sup>I goal as a fourth generation avionics complex and then by

executing only those technology insertion programs they build toward the goal.

**Phased or Goal-Oriented Approaches.** Creating a phased acquisition program takes a requirements planner with insight into long-range objectives for the weapon system. The planner must look beyond the immediate needs to requirements two or three modifications away. For whatever reason, planners find it far easier to devise a program for adaption of one new weapon or sensor than they do to plan a program that allows that same weapon or sensor to adjust for future growth. But here well-planned technology insertion earns its keep as a future investment.

Planners need to modify the bombers so that they remain in service for another 30 years or more, and so that they meet the demands of an increased conventional commitment. If we accept the technology insertion philosophies of chapter 3, we must realize the need to achieve an advanced complex to enhance the ability to integrate a wider variety of additional weapons systems. However, this goal embraces, without a doubt, a fiscally unrealistic mandate (that is, it is impossible to fund in total). To install a fourth generation complex in all bombers probably would consume the entire fiscal year acquisition outlay for several consecutive years. The planner, then, has a choice: Do nothing or strive for some of the goal. Hopefully, the planner will choose the latter.

We can use the cancelled SRAM II program as a real-world example of the decision-making process. SAC planned eventually to integrate SRAM II on the three bomber types which, of course, required new software and hardware. Unfortunately, for at least the B-1 (if not all three bombers), the software would not fit in the computer's memory. The planners recognized this problem and realized that it would recur each time the planners attempted a new integration. They wanted to insert upgraded computers, but, they were unable to obtain sufficient funding. As a result, designers planned to insert only enough new memory to cover the immediate needs of the SRAM II parenthetical integration. This is the memory that would fit in the existing box based on the old technology they planned to use. Though cancelled, this solution would have provided only a Band-Aid fix, adding nothing to future flexibility.

Had a long-range goal for a fourth generation avionics complex been identified from the start, planners could have used the SRAM II program as the first phase of a multistep process towards the final goal. With these longer range requirements established, the acquisition office could have obtained funding more easily than by advocating the development of a new VHSIC processor SRU with 10 times the amount of available memory for roughly the same price as it would pay to replace the sufficient core. In this way, the new VHSIC processor would have not only fulfilled the SRAM II requirement for additional memory, but it also placed the first building block on which the fourth generation complex would have been built eventually.

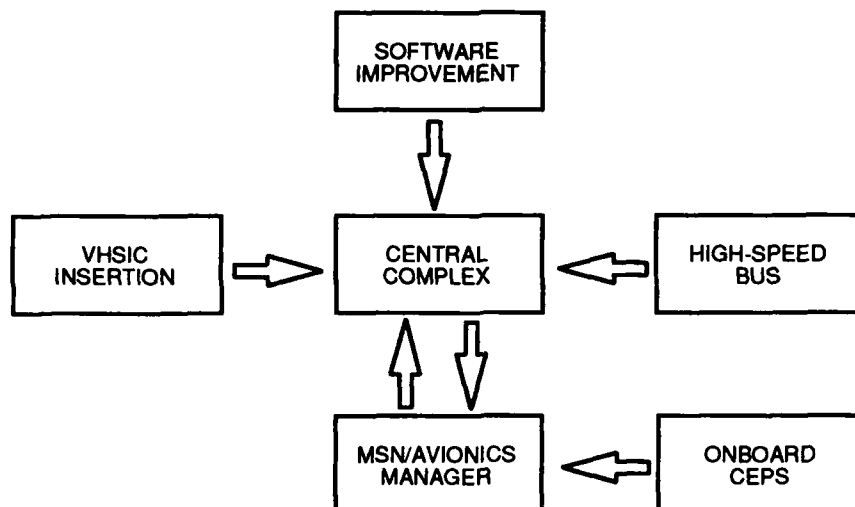
### The B-1B as a Technology Insertion Example

We are now ready to apply the chapter 3 concepts that use the B-1B exclusively. This statement does not imply that the B-52 or the B-2 does not also require technology insertion. To the contrary, these aircraft also could gain some added flexibility from well-planned programs to enhance their avionics. Using the B-1 only will simplify the discussion and eliminate redundancy. Also, using the B-1 is appropriate, since it is the midpoint between the less computer-intense B-52 and the more computer-intense B-2. However, B-1B concepts, though they could apply to most any other aircraft, may need to be down-scaled for one or up-scaled for another.

This section outlines a few concrete examples of practical technology insertions. Similar to the discussions in chapter 3, the specific technology insertion concepts discussed here provide improved avionics performance capacity, beginning with the easiest (and generally least expensive) modifications and leading to the more complex insertions. Consider figure 28 as an overview of these concepts. The central avionics complex serves as the hub of activity; and designers insert into the hub software modifications, faster processors, data communications, a system manager, and an onboard maintenance diagnosis. To further simplify the discussion, designers use such specific major systems as the offensive radar.

### Software

Due to its ease of manipulation, computer software is the logical place to open the door to the future. The central computers, particularly the navigation and weapons delivery computers, have reached their maximum



Source: The author.

Figure 28. Concepts for the Central Computer Complex

capacity in memory and throughput. Indeed, they are being used well above the level recommended by prudent computer system designers. Most experts in the field accept the premise that available memory and throughput should not exceed 70 percent of total capacity, but the B-1's computers often exceed this limit (see fig. 23). The need to double the memory to integrate SRAM II is evidenced by memory problems resulting from insufficient throughput and by unduplicative computer failures. Several software technology insertion concepts could eliminate (or at least reduce) these problems and, at the same time, provide for future growth. Where applicable, software technology insertion concepts are discussed in this paper within the modifications of the major subsystem, beginning with the central computers.

### **Concepts for the Central Computers**

As mentioned above, integration of the SRAM II weapon system, or actually any additional system, most likely would require modification of the existing central computer. The SRAM II program proposed the addition of two memory expansion cards with the same vanishing vendor problem. If designers had executed this program, they would not have had enough memory for the new missile, and they would not have had enough memory left over for anything else. Worse, this technology insertion program would have degraded both throughput performance and computer reliability due to the need for more hardware. Planners failed to consider the available options, beginning with simple software modifications, and they also failed to provide for P<sup>3</sup>I.

**Optimization.** The integration of SRAM II could have been accomplished easily by modifying the software, perhaps by simply eliminating such unused code as the useless ground moving-target track function and the limited utility auto map-cueing function. These two code optimization efforts, combined with writing both new and old code more efficiently, may have provided sufficient memory to allow the addition of at least one new weapon system like SRAM II. However, code optimization alone cannot provide enough capacity for future use beyond the addition of one new weapon.

**Stores Overlay.** A more radical software modification was needed for added flexibility during the SRAM II integration program; namely, designers could have inserted into the B-1B avionics software a modified version of the B-52 Integrated Conventional Stores Management System (ICSMS) software. For the B-1, the ICSMS concept could have been expanded to include all other weapons and such other weapon systems as additional sensors not just conventional weapons. Recall from chapter 2 that the ICSMS concept builds a stores overlay system. Currently, when planners load the central computers, they also load all possible weapons into RAM. In other words, in the old B-52 software (and the current B-1 software block 4.5), planners loaded the SRAM A, B-61, B-83, ALCM, ACM, and practice bomb weapons overlays in the same RAM, where they took up valuable space. But, planners shy away from allowing bombers to carry more than two different types of weapons on any one mission. In contrast, ICSMS permits the operator to load, as overlays,

only those weapons that bombers carry on a given mission. The overlays that planners enter during the preflight (initial) software loading stage bring in only the necessary weapons and sensors from storage, while overlays for other weapons and sensors remain in reserve (not in RAM). The stores overlay concept has at least three major benefits: (1) it frees a large amount of computer memory for other use, which also may have the residual benefit of reducing throughput demand (due to the need for less software to calculate through); (2) it requires only the addition of a weapons system overlay program for any new weapon or weapons system and will not require a major software block update; and (3) it uses Jovial software. Building stores overlays creates much more modular blocks of code and enhances the possibility of transporting weapons system software between bomber types. Stores overlay software comes with the one essential ingredient of flexibility, which allows the aircraft to adapt quickly to changing needs.

In 1991 Oklahoma City Air Logistics Center commissioned Boeing to study a stores overlay software system for the B-1B. Their initial estimates show impact up to 30 percent of the original software and require at least two years to complete the effort.<sup>1</sup> Boeing named the project Integrated Virtual Stores (IVS). When completed, IVS will provide the benefits listed in the above paragraph and thereby increase the flexibility of the B-1B.

**VHSIC Insertion.** Moving beyond software to the hardware concepts, planners believe VHSIC insertion into the central computer processors offers a much better alternative to the memory expansion cards proposed by the SRAM II program. For each computer, each VHSIC processor would replace 13 SRUs with one SRU and open the computers for expansion while providing at least eight times the current memory, reducing power consumption, cooling air requirements, and increasing reliability.<sup>2</sup> The magnitude of the impact and the change required to the avionics software depend on how similar it is to the current processor architecture. Designers would notice little impact on the software if they decide to use a reliability and maintainability-only VHSIC processor. This however would be shortsighted for the future flexibility of the aircraft. A well-designed VHSIC processor would allow future planners to take advantage of the central complex's increased speed and expandability. In other words, planners must design the VHSIC processor to allow the addition of a method to tie the core computers together for high-speed communication via a high-speed data bus (HSDB).

**A High-Speed Data Bus.** Even after central computers receive the benefits of VHSIC insertion, they would be hamstrung by the slow input/output (I/O) of the Mil-Std-1553B data bus. Core computers would continue to operate as separate entities, sharing data through what is essentially an ancient telephone system. If the VHSIC processor had the proper design, planners could enhance its aggregate computational capability by inserting a high-speed, direct communication line between each computer. With a HSDB tie, the central computers could perform as one unit, instantly sharing data and capacity. Because of the greater computation speed and memory provided by VHSIC insertion, combined with the improved I/O provided by the HSDB

insertion, planners could eliminate the existing (misnamed) mass storage device (MSD), or better, replace it with an onboard mission manager computer. (Note: For a description of the MSD, see chapter 2.)

**An Avionics System Manager.** After the central computers acquire the capability to accept higher speed information, planners could insert a current technology, high-speed, leading-edge, 32-bit architecture computer with true mass storage in the position now occupied by the MSD as the next major and logical addition. This computer would, as a minimum, calculate the active mission plan with the capacity to replan mission changes rapidly by using developed expert parameters. In this service the manager would roll in programs when necessary for execution and keep programs not currently needed updated and ready for immediate use. For example, the manager would load only that portion of the mission currently being executed—such as the takeoff and the cruise-to-refueling leg—then download this program and upload the low-level leg when the bomber reached that portion of the mission. In addition, the manager would allow the operator to select any portion of the mission to make changes or to get information. Aside from mission planning, the manager would store geodetic data to assist the terrain-following system if the radar failed, was jammed, or if the crew wanted to reduce radar emissions. The manager also should have control of the current offensive sensor (the radar) by preplanning sensor pointing schemes for automatic target search and by assisting in the integration of data between the existing radar and any new sensor.

Planners at the Flight Dynamics Lab at Wright Research and Development Center, under a program called Strategic Flight Management (SFM), have begun to study much of what the above paragraph suggested. The SFM program emanates from the knowledge-based Mission Replanning Model and Strategic Crewmen's Associate program. SFM seeks to develop onboard flight management, including an event-driven, real-time capacity to replan. The payoffs of SFM include increased survivability, fuel efficiency, overall flexibility, and an enhanced capability to locate and destroy relocatable targets.<sup>3</sup> Although SFM is aircraft-generic, Boeing uses the B-1B avionics complex as a typical avionics set in which it can insert SFM.

The insertion of a mission manager computer like that of the SFM program could be the foundation for a fourth generation, distributed, hierarchical architecture, avionics complex. If they plan well, planners can convert the mission manager computer into an avionics manager computer, while at the same time retaining the mission manager role. The only missing piece, after the mission manager is placed, is the insertion of the distributed system software architecture and whatever additional computer hardware the managing computer would require.

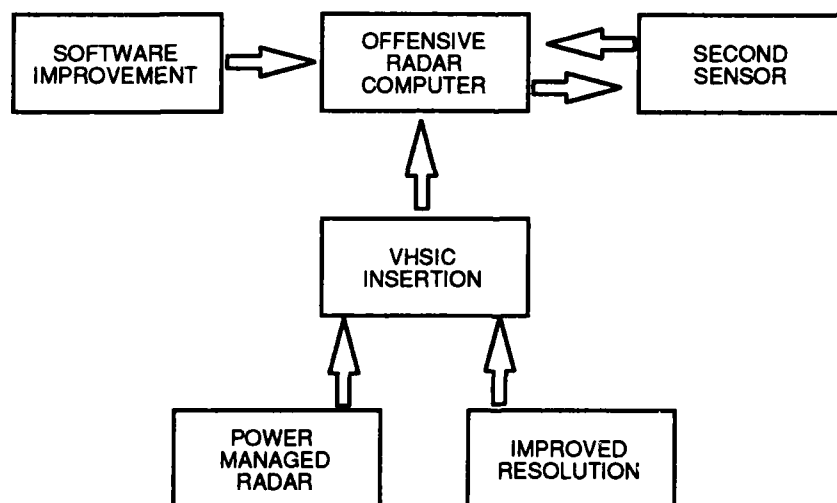
Phasing-in provides a cost-effective method for a distributed architecture. By first modifying the software, then adding VHSIC processors, a HSDB, a mission manager, and an avionics manager, the ultimate flexibility goal (i.e., creating a distributed avionics complex with unlimited growth potential) becomes affordable while providing timely enhancements to fulfill expanding

needs. Furthermore, this approach also allows such other aircraft systems as the sensors, navigation subsystem, and maintenance diagnosis system to stay in step with the expanding capacity of the central complex.

### Concepts for the Offensive Sensors

Similar to the central avionics complex, the sensor of the B-1B (i.e., the ground-mapping radar) has fundamental problems with both software and hardware. In chapter 2, the offensive radar functions was identified as a subsystem of the central complex. In effect, the radar subsystem is a microcosm of its central complex host. And, like the central complex, the heart of the offensive radar subsystem (i.e., the radar signal processor [RSP]) lacks sufficient RAM and throughput speed for significant additional tasks. Here again planners can make several software improvements to the radar system to take advantage of its existing superior performance qualities, and for the ultimate, phased-in technology insertions, the software improvements can be followed by hardware insertions. Figure 29 offers an overview of these concepts.

**Radar Software Concepts.** A comparable system provides the first place to seek out potential radar software improvement concepts. For example, planners may adapt the F-16's air-moving target track function to the B-1's unused, ground-moving target track function, creating the first bomber with a fire control radar similar to that of a fighter. This procedure provides many benefits to transporting this portion of the F-16's software onto the B-1. Specifically, planners can use the new track-while-scan fire control radar to maintain better formation for automatic tanker rendezvous, defensive situational awareness, and (most importantly) illumination of enemy airborne



Source: The author.

Figure 29. Concepts for the Offensive Sensor(s)

targets as a threat without weapons or support of a future lethal air-to-air defensive weapon.

The B-1's radar has other problems which software can solve. For example, Westinghouse Corporation, builder of the radar system, has proposed the insertion of new software that improves the nearly unusable real beam ground map (RBGM) mode of the radar.<sup>4</sup> The B-1B currently cannot clearly assess radar returns within a 10-degree cone around the nose of the aircraft. A sharper RBGM would eliminate this problem by attacking targets directly, enhancing damage assessment, and improving the performance of the navigation system. Once these software improvements have been made, the radar will have reached its greatest potential without hardware modifications.

**Radar Hardware Concepts.** The B-1B's radar signal processor, like the central computers, has nearly all available SRU slots occupied. Just as a VHSIC insertion would benefit the central computers, a VHSIC processor would benefit the RSP by decreasing the number of SRUs in the box, thereby reducing power consumption, cooling requirements, and increasing throughput speed and available memory. From a maintenance perspective, the RSP ranks as one of the most troublesome units. As mentioned in chapter 3, the RSP's low-reliability rate is caused by a significant amount of "could-not-duplicate" or "retest-ok" failures. Since one of the most likely sources of RSP failures relates to an overheat condition, a VHSIC RSP processor would undoubtedly provide a major reliability improvement. VHSIC insertion on the RSP also removes old, hard-to-procure parts and puts current technology in its place. The concept of VHSIC insertion already has been applied to the F-16 radar with success and therefore is a low-risk acquisition.<sup>5</sup> Beyond providing significant R&M improvements to the B-1B, VHSIC insertion would provide a path to such performance enhancements as radar power management and increased radar resolution.

**Power Management and Radar Resolution.** The current B-1B radar broadcasts at its highest power output, regardless of the distance of the target. This means, for example, that the radar broadcasts at maximum range during terrain-following, even though terrain up to only 10 miles out is being calculated. We can say much the same for ground-mapping during final aiming on bomb runs and during navigation updates. Operating in this mode unnecessarily exposes the aircraft and could have a serious impact in a hostile environment. With the improved throughput speed and computation capabilities of a VHSIC RSP, the radar could automatically broadcast only the power necessary to illuminate the target at the selected range.<sup>6</sup> Radar energy emissions therefore would be significantly lowered, reducing the likelihood of the enemy passively detecting the aircraft.

The reduced emissions concept was demonstrated by using a modified B-1B radar on a C-130 aircraft. The program called Quiet Knight tested this radar for low-probability of intercept (LPI) during terrain-following operations. Among other objectives, the Quiet Knight program sought:

To provide an LPI radar which is an integral part of a fused sensor scheme to combine an active sensor (radar) with a passive sensor. This combination of active and passive sensors is designed to further challenge [defensive] networks while providing a safe, ground-hugging terrain following system which effectively functions in any combination of day/night, adverse weather and/or adverse terrain conditions.<sup>7</sup>

Borrowing this proven technology from the Quiet Knight program and inserting it into the B-1 would be a simple task, since planners used the B-1's radar system to build the LPI system.

The addition of VHSIC to the RSP also can allow improvements in radar resolution (i.e., the quality of the radar presentation to the navigator). Although the current resolution, when in the high-resolution mode, suffices for navigation and bombing, the same resolution may be inadequate for future missions where smaller or well-hidden targets need to be identified. Westinghouse Corporation has successfully demonstrated improvements based on a VHSIC processor which provides a major increase in radar resolution.<sup>8</sup> The desirability of making such a modification on the radar is directly dependent on future missions, but note that, without the up-front technology insertion, improved resolution, which would help the B-1 to attack difficult targets, is not possible.

**A Second Sensor.** The B-1's offensive radar is one of the finest operational radar systems currently flying, and with the above software and hardware modifications, it has vast untapped potential. However, for likely future B-1 missions, a single sensor may fall short of the needed flexibility to adapt to precision target identification and destruction. What the B-1 needs then, even after the designers improve the radar, is another sensor or sensor suite integrated with the improved radar. If possible, the B-1 could use a second sensor to exploit such other target attributes as an infrared sensor to see heat sources rather than radar reflectiveness, or simply use it as a "second vote" during the identification process. Additional sensors may benefit the bomber in such other ways as a pilot night-vision enhancement or a laser target illuminator. Currently, a single radar sensor does not permit these types of activities.

The usefulness of the additional sensor(s) depends on the level of integration into the central complex. As such, the current avionics complex has little capacity to integrate other tasks. Therefore, planners would run the risk of overloading the computers unless the addition was autonomous (i.e., not integrated) if they attempt to add another sensor to an unmodified B-1 avionics complex. They would be making a mistake here since adding another sensor would undoubtedly increase the crew work load and contribute little to mission flexibility. However, inserting a VHSIC into the central computers, particularly with an avionics system (master-server) manager, makes complete sensor integration possible. An integrated sensor would relieve the operator of the excessive work load of simultaneously pointing two sensors to the same target. With an avionics system manager, the avionics could manage sensor pointing, and plan and execute target search patterns to assist in

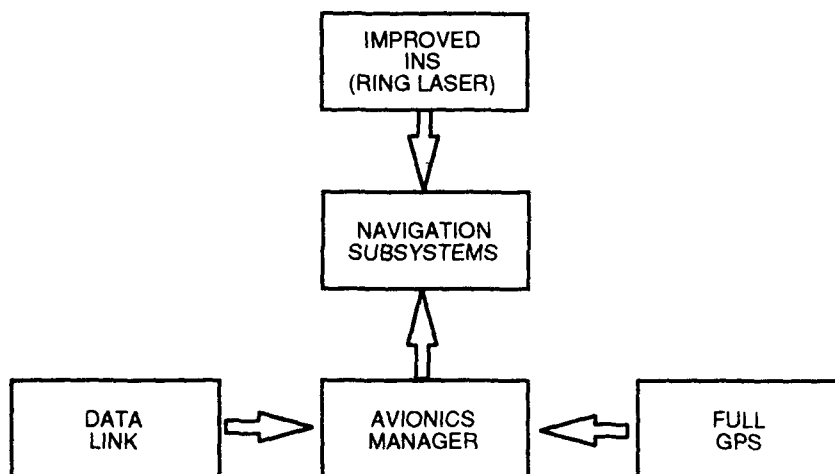
target location and recognition. Such a system would allow the B-1B to attack and destroy a wider variety of targets.

### Concepts for the Navigation System

The B-1B's navigation capability relies on two, fully integrated, inertial navigation systems (INS). For the most part, these two (or one on some aircraft) INS's provide sufficient capability to meet the demands of the nuclear mission, and as INS technology improves, planners can substitute new, higher quality INS's to meet the demands of this mission. However, to meet the requirements of an expanding conventional commitment, planners must improve the B-1B's navigation system in two areas: integration of a global positioning system (GPS) and data-link communication with the navigation computers. Figure 30 illustrates concepts to enhance the navigation system.

As demonstrated by the Gulf War, the military is becoming increasingly dependent on GPS. Yet, only part of the B-52s and none of the B-1Bs have a GPS. Rational thinking calls for integration of GPS data into the avionics. GPS will offer reliable navigation data over water, provide backup data to the existing INS's, and give position information for more accurate weapons delivery. Still, as with the radar and other systems, fully integrating the GPS is most likely outside the capacity of the current avionics complex. Again, if planners insert an avionics system manager computer, the aircraft can quickly and easily integrate a GPS.

Likewise, Desert Storm proved the value of clear and direct communications, a capability which only the B-1 enjoys with voice communications. As suggested in chapter 1, to enhance conventional war fighting, planners must provide the aircraft with the capability to data-link revised mission plans and



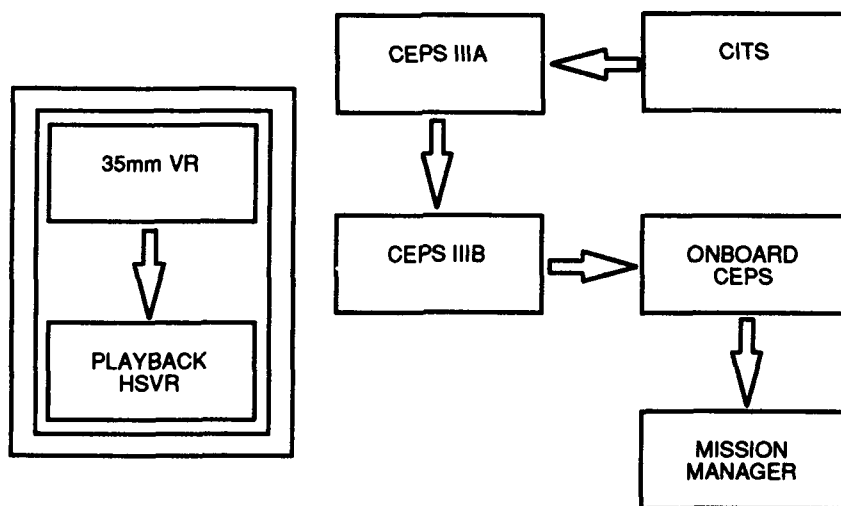
Source: The author.

**Figure 30. Concepts for the Navigation System**

target information from headquarters directly to an onboard mission-planning system. Here, the insertion of an avionics mission manager holds the key. If planners insert an onboard mission-planning system in the place of the MSD as proposed above, they could install a data-link communication modem that could transmit data directly into the aircraft, where the crew reckons and presents it for selection of appropriate action. Without an upgrade to the avionics central complex, little possibility exists that the computers could handle the volume of information required to execute rapid mission changes, thereby robbing the B-1 of an essential ingredient of flexibility.

### Concepts for Data Collection and Maintenance Diagnosis

Although computers record large amounts of data during a B-1 mission, they do not make the data available for immediate use by either the flight crew or the maintenance personnel. This deficiency takes on particular significance during postflight analysis, where the data is either poor quality or difficult to analyze. Data collected by the Centrally Integrated Test System (CITS) occupies an unfiltered data dump. Planners have formatted the navigation and weapons data storage unit incorrectly, making it unusable; and data collected on the early 35-mm video recorder is distorted and poor photo quality. Each system could benefit from some form of technology insertion, if for no other reason than to improve general operations. More importantly, data retained by the CITS and the video recorder could provide the aircrew with valuable in-flight data if properly filtered. Figure 31 depicts an overview of technology insertion concepts for improved data collection and analysis.



Source: The author.

**Figure 31. Concepts for Data Collection/Maintenance Diagnosis**

**An Onboard Maintenance Expert.** The CITS expert parameter system (CEPS) discussed in chapter 2 currently has the capability to record aircraft malfunctions, but it can only analyze offensive/defensive system avionics malfunctions. CEPS relies on an "expert" data management system to continually update its knowledge base as it interacts with maintenance technicians in the troubleshooting process. In the current system, CEPS captures this expert knowledge and makes it available to the ground technician in the form of computer-provided maintenance advice. The CEPS concept has merit beyond ground maintenance. If the data being recorded for later analysis were analyzed on board in real time, the data would give maintenance technicians instant postflight information for quicker aircraft turns, and the aircrew would have a valuable tool for in-flight decision making.

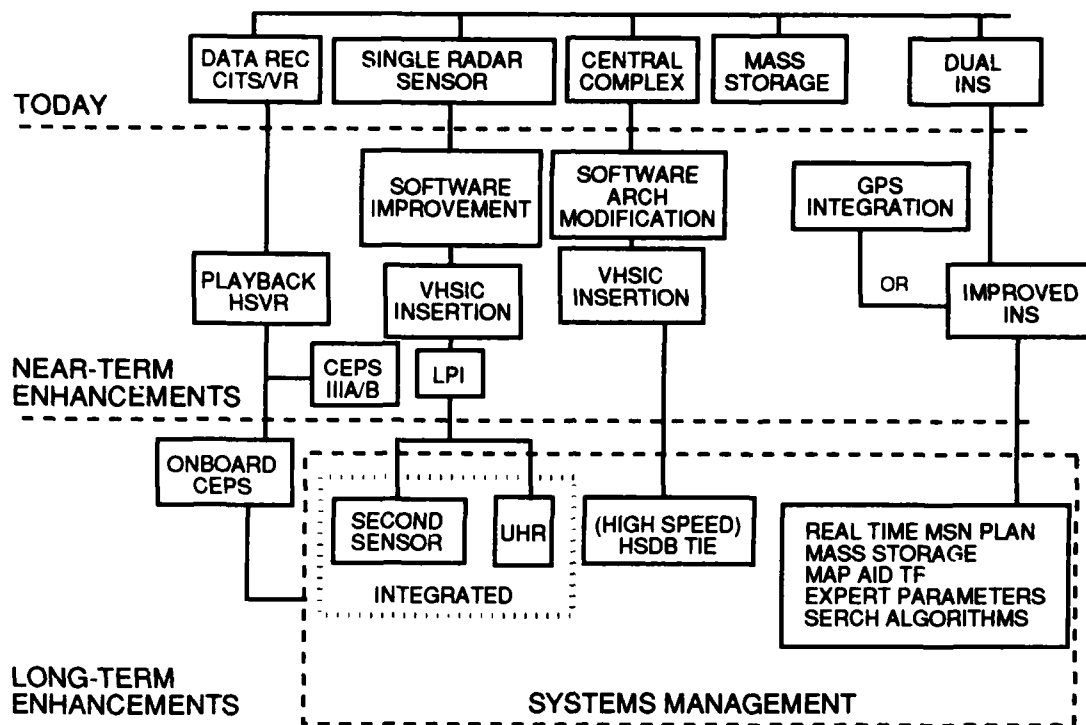
If CEPS were on board, as systems degrade due to malfunctions or as they totally fail, the aircrew could use the expert knowledge to make timely decisions on the dispensation of the mission or to consider changes in tactics to compensate for lost equipment. Even better, delivering CEPS data directly to the mission manager computer would complete the loop in mission planning. With CEPS and the mission planning computer working together, the crew would have complete knowledge of their aircraft problems, and the mission planning computer would be able to present to the crew the options available for continuing the mission, thereby adding to the crew's flexibility.

**A Playback Video Recorder.** The current 35-mm video recorder has poor quality and has little analytical use. In addition, 35-mm film complicates handling, developing, and displaying the collected data. It also loses valuable data due to procedural errors or malfunctions. Even further, the recorded display does not parallel what the operator saw, because it was recorded in the backup display mode and not in the same mode (real mode) used by the navigator.

A much better medium for recording radar video is to insert an off-the-shelf, current-technology, high-resolution video recorder (HRVR). The HRVR offers ease of handling, instant feedback during postflight, a more reliable system, the potential to record multiple video sources (if other sensors were added to the B-1), and, if well engineered, the possibility of in-flight playback. The instant playback concept provides the navigator with the opportunity to review immediately the collected images for improved target identification or to assist in a strike decision. Once more, the flight crew has acquired added flexibility through technology insertions.

### **Concepts Taken Together**

Figure 32 shows the concepts outlined above in a phased approach. The top of the chart depicts the current B-1 system. The enhancements listed for the near term may be necessary to fulfill the needs of the B-1 in a future conventional war. Planners engineer each near-term enhancement with the ultimate long-range objective of inserting a master-server computer to act as a system manager to provide a distributed avionics complex with unlimited growth. A system designed in this manner enables the B-1B, or any similar



Source: The author.

**Figure 32. B-1B Avionics Roadmap**

aircraft, to adapt quickly to changing circumstances and needs. With an unlimited performance capacity and an open avionics architecture, designers can tailor the aircraft to meet specific mission needs by adding or subtracting such systems as weapons, sensors, and ECM equipment.

## Comparing Needs to Programs

As you can see from the above discussion of potential B-1B technology insertion concepts, an extensive list of candidates to choose from abound, but none of them is free. It is likely that the planner will have to do just that—choose some of the concepts and not all of them. How can the planner identify choices? What criteria should the planner use? The only answer is that the planner must compare the program to the needs. In other words, the program must fill specific requirements.

Using the requirements outlined in chapter 1, we can determine how well the B-1 technology insertion concepts discussed fulfilled the needs. Remember from chapter 1 that the basic categories of requirements for conventional bombers were (1) improved target destruction capability, (2) improved communication, and (3) improved onboard mission management. Table 7 shows the

**Table 7**

**Bomber Needs vs Programs**

NEED	DEGREE OF COMPLEXITY*	TIME FRAME	BASIC INSERTION PROGRAM(S) NEEDED
<b>IMPROVED TARGET DETECTION</b>			
• Auto Search and Target ID	7	LONG TERM	CC** VHSIC/MISSION PLANNER/AVIONICS MANAGER
• Improved Weapon Integration	4	NEAR TERM	SOFTWARE/CC VHSIC
• Full GPS Integration	3	NEAR TERM	CC VHSIC
• Improved Radar Resolution	4	NEAR TERM	RADAR SIGNAL PROCESSOR VHSIC
• Addition Sensor(s)	5	NEAR TERM	CC VHSIC
<b>IMPROVED COMMUNICATIONS</b>			
• InterAircraft Data Link	5	NEAR TERM	MISSION PLANNER
• Space System Headquarters Data Link	5	NEAR TERM	MISSION PLANNER
• Improved Joint Interoperability	3	NEAR TERM	PERHAPS NONE (JUST BETTER APPLICATION OF STANDARDS)
<b>IMPROVED ONBOARD MISSION MANAGEMENT</b>			
• In-Flight Replanning	6	NEAR TERM	CC VHSIC/MISSION MANAGER
• Sensor Management	7	LONG TERM	CC VHSIC/MISSION MANAGER/AVIONICS MANAGER
• Improved Data Recording	5	NEAR TERM	SOFTWARE/MISSION HIGH RESOLUTION VIDEO RECORDER
• In-Flight Maintenance	6	LONG TERM	ONBOARD CEPS/HIGH RESOLUTION VIDEO RECORDER/MISSION MANAGER

\*COMPLEXITY SCALE: 1-10  
(SIMPLE TO COMPLEX)

\*\*CC—CENTRAL COMPUTER

**SOURCE:** The author.

requirements under each category and enables the reader to assess whether a concept listed in the section above meets the requirement. Note that technology insertion programs can fulfill each of the needs; some needs, however, are easier to fulfill than others. The column labeled "Degree of Complexity" shows a scale that ranges from 1 to 10, with 10 being the most complex. The higher the numbers in this column, the more careful the planners must be to ensure that they formulate long-range goals from the beginning of each project.

Just as technology insertion holds the key to the future of bomber flexibility, sound acquisition planning is the key to ensuring that the technology inserted provides for that flexibility. The concepts discussed above show that well-planned, goal-oriented technology insertion can give the B-1B a promising future as a quickly adaptable aircraft. The B-52 and the B-2 can benefit equally from such activity, but only if action is taken today to prepare for tomorrow.

#### **Notes**

1. Briefing, Boeing Aerospace, subject: "B-1B Integrated Virtual Stores Software Modification Study," Oklahoma City Air Logistics Center, Oklahoma City, Okla., 1991.
2. Boeing Aerospace, "B-1B VHSIC Processor," Oklahoma City Air Logistics Center, Oklahoma City, Okla., 1991.
3. A. David Churchman, Boeing Defense & Space Group, "Strategic Flight Management Integration Study" contract no. F33601-88-D-0011, Flight Dynamics Laboratory report, Wright-Patterson AFB, Ohio, March 1991.
4. James Williams, Westinghouse Electric Corporation, "B-1B ORS Improvements," briefing to Headquarters SAC and Oklahoma Air Logistics Center, Summer 1991.
5. Ibid.
6. Westinghouse Electric Corporation, "VHSIC Advanced Radar Signal Processor (ARSP) Capabilities Study, Rev A," Service Engineering Report item B001 DI-S-3601A, Baltimore, 26 April 1991.
7. Westinghouse Electric Corporation, "Quiet Knight LPI Radar Final Report," Baltimore, 16 January 1991, 1.
8. Westinghouse Electric Corporation, Service Engineering Report item B001 DI-S-3601A.

## Chapter 5

### Recommendations Toward a Better Bomber Force

A recommendation made in a world that changes as rapidly as ours would yield more prophecy than it does science. Over the years, since World War II and since the invention of the nuclear bomb, few observers criticized the need for bombers. Now, more than ever before, the utility of the bomber is being questioned along with its existence as part of America's offensive forces. At the same time, based on the defensive philosophies of *Global Reach—Global Power*, the Air Force visualizes more diverse missions for the bomber than simply standing on nuclear alert. Primary among these missions is a much larger role during conventional wars. In the words of Gen G. Lee Butler:

The role of the bomber in future conventional warfare cannot be overstated. Its unparalleled responsiveness, payload and flexibility, coupled with a capability to range to globe for the United States without enroute or host nation support, make the bomber a unique and unreplaceable instrument of national power. For a variety of reasons, for the past 45 years, the inherent conventional role of the bomber has been called upon only episodically. The emphasis has been on its nuclear deterrent role. While that mission will continue to loom large for years to come, it is clearly time to reinstitute the full conventional capacity of the nation's bomber fleet, especially as its numbers shrink in the years ahead.<sup>1</sup>

Making recommendations to enhance bomber capabilities to help fulfill General Butler's vision requires that planners weigh the factors of increasing uncertainty and predicting future weapons needs, while balancing these needs against a shrinking defense budget.

We feel certain however that planners need to make some changes if the bomber is to remain credible for use in future conflicts. Making no changes to the bomber's capabilities will, without a doubt, provide us with an aircraft with little usefulness if a conventional war is fought in the late 1990s. According to General Butler, the bomber's advantages include unparalleled responsiveness, payload capacity, range without support, and flexibility. While our bombers have formidable power today, particularly for nuclear warfare, proliferation of modern weapons and defense technology is rapidly overcoming their flexibility, which is perhaps the most important of their advantages. Therefore, first among the recommendations is to make acquisitions to augment bomber flexibility through well-engineered technology insertions. After this, all other needs of the bomber will be much easier to fulfill, making enhanced flexibility the first and last recommendation.

## **Flexibility for the B-52**

The B-52 has demonstrated its adaptability after more than 30 years of dependable service. This is a remarkable achievement considering all that has occurred during its lifetime. What has kept the aircraft in the war, so to speak, is its "truck-like" performance characteristics coupled with periodic upgrades to its heart—the avionics. The last major upgrade, made in the early 1980s, put state-of-the-art digital electronics into the aircraft, which allowed the carriage and control of air launched cruise missiles. This acquisition made the B-52 the only bomber participant in the conventional Gulf War to use these same missiles. The B-52's time-proven design establishes it as the continuing backbone of our bomber fleet.

## **Why Teach an Old Dog New Tricks**

Still, some experts argue that the B-52 is worn out and should be retired. With increasing age comes increasing difficulty in maintaining the airframe and the avionics that were not modernized in the early 1980s. The critics claim that upgrading the older avionics and executing other technology insertion programs is chasing good money after bad. They further argue that the size of the bomber force may be too big in our less threatening world, so why waste money on a system we do not really need.

Unfortunately, regardless of unfolding maintenance problems of the aging B-52, the simple fact remains that it is still the most versatile conventional bomber in our inventory. It can currently carry a wider variety of ordnance than the B-1 and can fill the gap, while the B-1 acquires additional weapons and the B-2 matures to operational status. Frankly, however, it is difficult to justify making the B-52 the target of the first (or highest priority) technology insertion programs to improve flexibility. Only one argument defends such a program—the B-52 is a quantified commodity. This means that, because of the age of the B-52, there are few unknowns regarding aircraft and avionics performance characteristics. Minimizing the unknowns simplifies the full-scale development process during procurement. Nevertheless, this argument is probably not strong enough to pass the scrutiny of the congressional watchdogs, and it is unlikely they would approve of a major modernization program.

But a loophole may help the old dog to learn new tricks. The loophole holds that the B-52's avionics, particularly the central computers, parallel the B-1B. This means that changes made to the computers on the B-1B most likely will easily transport to the B-52. Say, for example, that phase 1 of a B-1 avionics upgrade was a VHSIC insertion into the central computers. It is reasonable to expect planners to insert the same VHSIC processor into the B-52. In fact, the VHSIC processor's price most likely would decrease if more were produced to cover the number required for both the B-52 and the B-1B. In a

similar way, other upgrades to the B-1 may apply to save money, to increase commonality, and most importantly to stretch the life of the "old dog."

### **B-52 Recommendations**

One must make recommendations for the B-52 with an eye on both the aircraft's life expectancy and the political aspects of the perceived dichotomy of placing high technology in an old bomber. As is, the B-52 is an excellent conventional bomber, and it will continue as such for many more years. Other than the unproven B-2, no other aircraft can carry cruise missiles as well. This capability will keep the B-52 as the bomber of choice for several more years, or until the B-1B is outfitted with improved conventional weapons.

With this thought in mind (that is, outfitting the B-1), the most relevant recommendation for the B-52 is to carefully watch for upgrades to the B-1's avionics. To keep the B-52 credible through the turn of the century, planners must increase the computer capacity. In addition, to maintain the flexibility needed to conduct robust conventional missions, the aircraft should have an above-system mission planning computer, improved communication, and full GPS integration. These rather simple improvements to the avionics are obtainable through technology insertion into the existing system without major disruption to the current architecture.

Therefore, for improved flexibility, the B-52 should adopt B-1B avionics improvements. First on the list for the B-52 is a VHSIC insertion to increase the memory and throughput capacity of the central computers. From this basis, the data transfer units (DTU) should be replaced when a mission manager computer retains an improved ground-to-aircraft data transfer and has both mass storage and computational capabilities. These changes to the B-52's system provide much growth potential and, with the existing software architecture, quicker integration of new weapons and systems. These modifications also help to relieve the vanishing-vendor maintenance problem of the present central computers.<sup>2</sup> One additional benefit comes when (or if) the B-52 is retired. That is, if the B-52 adopts a B-1 VHSIC processor, when the B-52 is finally laid to rest, planners will have an abundant new source of B-1 computer parts. The most important lesson for planners to carry from these recommendations is to insist that the B-52, B-1B, and B-2 are considered together when they plan upgrades. In other words, the B-52 program manager should be standing in the room when planners decide to upgrade the B-1B or the B-2.

### **Flexibility for the B-1B**

Planners must consider many factors when they make recommendations for the B-1B. Unlike the B-52, the B-1B has not had the opportunity to prove itself in combat. When Operation Desert Storm began, planners had not even

finished testing the B-1B's only planned conventional weapon—the 500-pound Mk-82 bomb. Flight testing has shown however, that the B-1 has the makings of a versatile bomber like the B-52. On the other hand, as the press has repeatedly reported, the aircraft is not without problems. But, the B-1's biggest problem is not the reported developmental growing pains all aircraft suffer, instead its biggest problem is the congressional prohibition on enhancements above the baseline requirements. Because of this funding cap, which was in place throughout the 1980s, designers could make no major avionics modifications to the aircraft.

### **Removing the "Interim"**

Contributing to the constraints on enhancing the B-1 was the belief that it was an interim bomber, one built to fill the gap between the B-52 and the B-2. This notion surfaced when President Ronald Reagan resurrected the B-1 at the same time he initiated the B-2 development program. Many observers then assumed the B-1B would remain operational until the B-2 could be fielded. However, program uncertainties and the fact that the United States purchased only 20 B-2s indicate that the B-1 will remain part of the inventory indefinitely. Thus, with the funding cap and the interim bomber tag removed, designers can begin the final development of the B-1 and allow the aircraft to achieve its potential.

### **The B-1 and START**

The Strategic Arms Reduction Treaty (START) also constrains development of the B-1B. Specifically, the treaty prohibits the B-1 from carrying nuclear, air launched cruise missiles.<sup>3</sup> To comply with the treaty, the aircraft cannot be configured to carry cruise missiles either internally or externally. Thus, planners cannot reposition the bulkhead between the forward and intermediate bomb bays to its forward position to create a bay large enough for cruise missiles. Also, this inability means that cruise missile pylons cannot be loaded on the aircraft or even stored at a B-1 base. Because of this, START restricts the aircraft to certain types of weapon system acquisitions.

Although the START restrictions appear generally to reduce the aircraft's future flexibility, they may actually benefit the aircraft in the long run. Because of these constraints, the planners cannot thoughtlessly attempt to adapt the B-52's weapons to the B-1. Instead, they must carefully examine other avenues to improve the B-1's capabilities, particularly its conventional capabilities. The meticulous planning process required in the constrained environment of the B-1 will likely result in recommendations for enhancements that are more enduring.

### **B-1B Recommendations**

What the B-1 needed first and foremost, for future warfare, is additional computer power. Persons familiar with the aircraft may be surprised by this recommendation. Followers of press releases may have identified the highest

priority as improved electronic countermeasures or a new conventional weapon. But these acquisitions treat the symptoms instead of the cause. Though it is true the aircraft could benefit from these improvements, it would be far better in the long run if the enhancements began with improved avionics, the basic building block for flexibility.

Additional computer power comes in many different forms, but the best approach for the B-1B is a simultaneous upgrade to the avionics software architecture and insertion of VHSIC into the central processors. These two modifications provide the much-needed relief for memory, throughput, and maintenance problems, and, if properly engineered, lay the path for such additional avionics expansions as a high-speed data bus and an onboard manager computer. Beyond these performance improvements, the software and VHSIC insertions allow the desired improvements in electronic countermeasures and more simplistic integration of additional conventional weapons. And, as mentioned above, planners could use a well-designed VHSIC processor on the B-52.

After they modify the avionics foundation, planners should make their next acquisition priority, as a minimum, the insertion of an onboard mission manager computer with associated integration of GPS and an advanced communication data link capability in place of the MSD. A better plan, however, would be the installation of an avionics system manager. For the greatest flexibility, the B-1 should integrate a master-server computer that contains the attributes of the mission planning computer and acts like the master computer of an advanced distributed avionics system to provide the aircraft with a fourth generation avionics complex. With this system, the B-1 has unlimited growth potential and the flexibility to add whatever weapon system is needed and to adapt to whatever missions may develop.

## **Flexibility for the B-2A**

At the writing of this document, the B-2 is a tentative acquisition. President Bush limited the production of B-2s to 20 in his 1992 State of the Union Address, and the aircraft is not without major criticism. Hopefully, these obstacles will not overshadow the enormous potential of the B-2. The aircraft already contains such features needed in the B-1 and B-52, as larger memory computers and the beginnings of an onboard mission manager. If the B-2 proves itself during flight test, it will be an outstanding complement to the other two strategic bombers.

### **Before It's Too Late**

Still, for the B-2 to meet the demands of an increased variety of missions, planners may need to modify the avionics. For example, the lack of throughput and I/O speed undoubtedly will constrain the aircraft's capacity to integrate future weapon systems. Additionally, the small number of stealth

bombers being fielded makes the availability of spare parts and logistics concerns a continuing problem. Planners could reduce these problems if they shared some of the B-2 software and hardware with other bombers. Modularity and commonality then may mean the difference between long-term survival of the B-2 and its early retirement.

Planners must modify the B-2's avionics now, not after they have fielded the aircraft. They would find it far more simple to insert improvements into an aircraft in the production phase rather than after deployment. During production, the development and testing facilities are in place, the aircraft are available, and operational flight procedures (which often change with new equipment) are not yet established. Delaying the needed technology insertions until the out-years may make it unaffordable.

### **B-2 Recommendations**

The B-2 Stealth is probably the most difficult bomber to make recommendations for. This difficulty exists partly because of the Stealth's highly classified nature in the early years, but mainly it exists because planners have not completed the aircraft (at the time of this writing). They still have much to learn about the performance characteristics and avionics of the aircraft. However, this writer can offer some general recommendations.

Similar to the B-52 and the B-1, the B-2 needs plenty of avionics growth capacity to add new or needed weapon systems. The best way for planners to ensure that the growth potential of the B-2 remains available is to insert the high-speed I/O into the central complex and develop the mission planning computer into an avionics system manager for distributed avionics. Rebuilding the B-2's avionics in this manner eliminates the possibility that it will run out of computer capacity and increases the likelihood that it will share B-1 or B-52 software and hardware.

## **Funding Flexibility**

However, inserting the required technology is neither free nor inexpensive. For obvious reasons, planners cannot go to the local computer store and buy a new, modern-technology central computer for a bomber, because they must adhere to military standards. But these military standards, if properly applied, can provide the benefit of increased likelihood of reusability between weapon systems (in our case bombers) and thereby reduce costs, if planners insert technology on all three bomber types. Consolidating the acquisition programs for the B-52, B-1B, and B-2 could reduce the price of modernizing their avionics.

How much would technology insertion cost? This answer, of course, depends on the nature of the program. As a rule of thumb, the program becomes more expensive as planners modify more hardware than software. Typically, modifying just software to add a new capability usually will cost tens of

millions of dollars for a fleet retrofit, whereas modifying hardware will sometimes cost into the hundreds of millions. In 1989, for example, the Oklahoma City Air Logistics Center estimated that the cost of integrating GPS hardware on the B-1 with mostly software would be approximately \$70 million. Likewise, a 1989 General Accounting Office report to the House and Senate Committees on Armed Services estimated the cost of B-1 avionics system enhancements at \$357.1 million.<sup>4</sup> Though these figures are not well researched and may not be accurate, they do illustrate the amount of money various technology insertions could cost.

Realizing the rather large sums of money needed for improving the flexibility of bombers, the next question is, Where can someone find this kind of money? Of course no simple answer exists. However, herein lies the attractiveness of procuring improved avionics by using a phased-in approach: buy improvements step-by-step, with each step adding capacity (and flexibility), but building toward a long-term objective. For example, suppose Congress supports the acquisition of a new smart weapon for the B-1B. Naturally, the new weapon will require additional software and hardware. When building the acquisition game plan to integrate the new weapon, planners should insist on a simultaneous avionics system improvement to include such things as a VHSIC processor insertion into the central computer, GPS integration, and an onboard mission planning computer. Then, later in the life of the B-1, when the timing is right for additional upgrades, the foundation will be there to build on. The alternative to the phased-in approach is funding an entire fourth generation avionics suite in a bomber—and this purchase will likely cost in the billions of dollars and will therefore be unacceptable. Funding an advanced system in phases is the only logical approach.

### **The Mission-Tailored Bomber**

In conclusion, the primary goal of the bomber force in this rapidly changing world is to respond to a wide range of missions. A bomber may be expected to be on nuclear alert one day and then to hunt for and destroy hidden conventional ballistic missiles the next day. Our bombers, procured during the cold war when the nuclear mission dominated, lack the flexibility to respond to these rapidly changing circumstances. What planners need in conclusion is enhanced flexibility for our bombers; they need the capability to have bombers quickly tailored for many roles. Simply adding another weapon or sensor will not provide this tailoring ability, but planners can add this capability through well-thought-out, well-engineered technology insertion.

Since modern-day aircraft derive their capabilities from their avionics, the place to begin is to insert flexibility into bombers through the computers. The B-52, B-1, and B-2 have similar computers and avionics architecture. By extracting the good characteristics each bomber possesses to share between

them and by exploiting the commonalty of their missions as well as their equipment, planners can create a better-prepared bomber force.

Ultimately, with the enhanced capabilities provided through technology insertion, planners can tailor bombers to meet the changing daily needs of the field commander. No longer will planners restrict aircraft to limited participation in war because the weapons they can carry do not fit current needs. With the advanced avionics it obtains through clever technology insertion, a bomber will be able to quickly integrate weapons or weapons systems that fit its aerodynamic profile. In other words, planners can tailor the bomber to fit the war: perhaps dropping 50 dumb bombs one day, and the next day they may use multiple sensors to hunt and kill missile-carrying vehicles. Whatever the challenge may be in the late 1990s, the bomber can prevail if planners begin today to insert the flexibility bombers will require tomorrow.

#### Notes

1. Gen G. Lee Butler, CINCSAC, testimony to the House Armed Services Committee, 20 March 1991.

2. U.S. Department of State, Bureau of Public Affairs, *START—Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms*, Dispatch Supplement 2, no. 5, October 1991, 254–55.

3. U.S. General Accounting Office, *Strategic Bomber: B-1B Cost and Performance Remain Uncertain*, report to the chairmen of the House and Senate Committees on Armed Services, February 1989, 30–31.

4. Ibid.